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AC-DC POWER PROCESSOR, TYPE I.(U)
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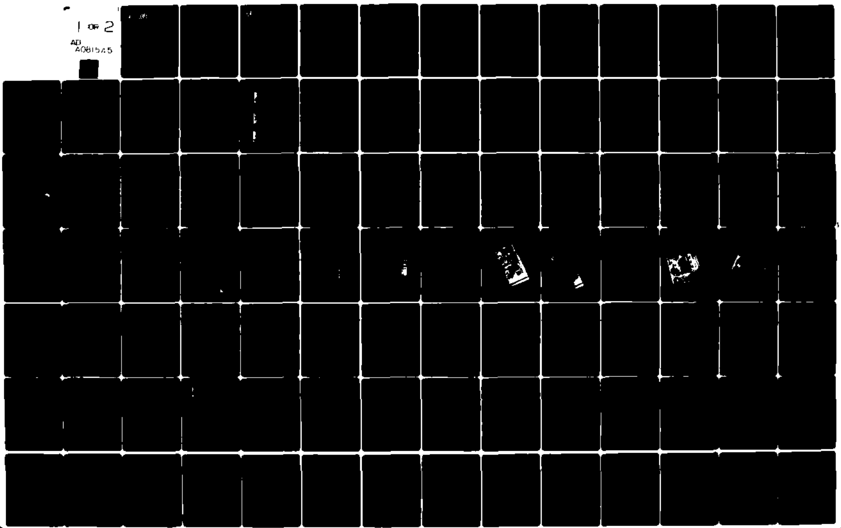

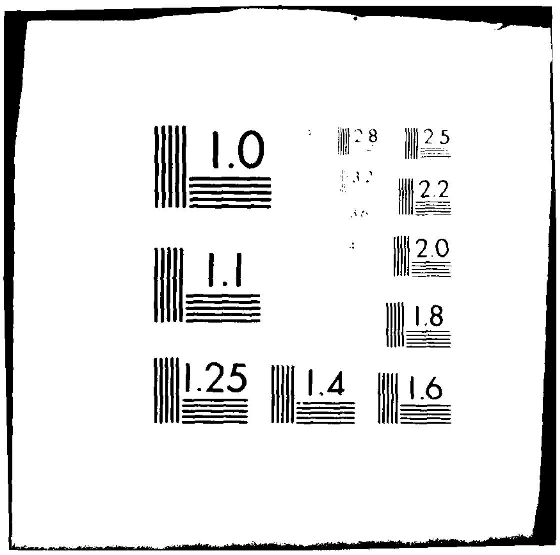
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Research and Development Technical Report

DELET-TR-76-1336-F

AD A081545

AC-DC POWER PROCESSOR TYPE I

JOHN J. BIESS
TRW DEFENSE & SPACE SYSTEMS GROUP
POWER CONVERSION ELECTRONICS DEPARTMENT
REDONDO BEACH, CA 90278

NOVEMBER 1979

FINAL REPORT FOR PERIOD MARCH 1976 - MARCH 1978

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Research and Development Technical Report

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Series Resonant Inverter
Precision Regulation
Dual Loop Feedback Control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The AC-DC Power Processor Type I Power Module furnishes 0-100ADC over an output voltage range of 24 to 32VDC from a 120/208 3Ø 50/60/400Hz power source. Remote output voltage sensing at the load circuit is provided to eliminate the IR drop of the power distribution cabling between the power module and the load. The power module can also be used for battery charging from 5 to 100A.

A thyristor series LC resonant inverter power stage is used to provide the output power control and regulation, input/output ground isolation and protection of the power thyristor.

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The power supply is constructed in accordance with the shelter-installed, mobile GE equipment for shelter or van use without the use of fans for cooling. The internal electronics are modularized according to circuit function with provisions for easy removal and repair.

Reliability, efficiency, weight and size achieved are approximately 12,200 hrs (MTBF), 86.6% 88.8 lbs and 2.0 cubic ft (front panel 19"x10.5", main chassis 17"Wx18.9"Dx10"H).

PREFACE

The electrical design of the AC-DC Power Processor was performed by D. L. Cronin. The Mechanical and Thermal Design was performed by Mel Monegan, John Bertero and Efren Mendez. The Electrical Testing and Evaluation was performed by L. Y. Inouye. The Electromagnetic Interference Tests were performed by Hector Huertas.

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1. INTRODUCTION.

The U. S. Army Electronics Research & Development Command is developing standardized power processing modules for application in the different power subsystem configurations being planned for digital equipment in communications, data handling, surveillance, and weapon systems. This report presents the results of work performed under Contract DAAB07-76C-1336 for the U. S. Army Electronics Research & Development Command to develop the AC-DC Power Processor Type I Power Module.

The Original Demonstration Model of the AC-DC Power Processor was developed under Contract DAAB07-70-C-0245 in 1969. It was composed of two phase displaced series resonant power stages operating at approximately 7kHz repetition rate. The unit had three problems areas: (1) high acoustic noise level, (2) high component temperature, and (3) high electromagnetic interference levels.

The specific objective of this contract was the development of an Advanced Development Model AC-DC Power Processor that would provide precision; transient free 28V, 100A output power from a 120/208VAC 3Ø 50, 60, 400Hz input power bus; improve reliability and performance; and reduce development, production and logistic costs.

A study was made to reduce the acoustic noise from the power processing delivery multikilowatt of output power. As a result of the review, a four stage phase displaced power module configuration, each operating at 10kHz, was selected in order to reduce the peak currents in the power processor. The high peak currents flowing in the magnetic and capacitor components contributed to acoustic sound level emitting from power processing equipment. The phase displaced operation minimizes output filtering requirements since the effective output ripple frequency is 80kHz.

A new thyristor series resonant inverter power stage was developed that would improve the DC to DC conversion efficiency. The series resonant inverter power stage includes an energy control system where excessive LC resonant tank energy is fed directly to the output load. This helps to improve the overall efficiency of the power stage.

A complete 3.2KW AC-DC Power Processor was designed, breadboarded, and tested. The reliability analysis predicts a mean time between failure of 12,200 hours. The complete electrical design was packaged to fit into a 19 inch rack panel. The unit was fabricated into five electrical subassemblies and four auxiliary mechanical subassemblies.

The dimensions of the unit are 10 inches in height, 17 inches in width, 18.9 inches in length and weighs 88.8 lbs. The front panel dimensions are 19 inches wide and 10.5 high. The unit is designed to operate with free convection cooling. A summary of the test results are presented in Table I.

The advanced development model of the 3.2KW AC-DC Power Processor fulfills the need for standardized U.S. Army Power Processing Equipment.

The following sections present a discussion of the design philosophy and theory of operation (Section 2), a discussion of the advanced development model electrical and mechanical design (Section 3). Section 4 summarizes the electrical, thermal, electromagnetic and acoustic test results.

Two AC-DC Power Processor Advanced Development Models were delivered to the U.S. Army Electronics Research & Development Command, Fort Monmouth, N.J., as part of Contract DAAB07-76C-1336.

TABLE I - SUMMARY OF 3.2KW AC-DC POWER PROCESSOR TEST RESULTS

		LOCAL SENSE	REMOTE SENSE*
OUTPUT REGULATION DUE TO LINE (120/208VAC ± 10% 3 Ø) & LOAD (0-100A)	eo = 24V	±96mV	±10mV
	28V	±95mV	±10mV
	32V	±95.5mV	±10mV (eo = 29VDC)
OUTPUT REGULATION DUE TO TEMPERATURE (-25° TO +145°F)	eo = 28V	±102mV	
OUTPUT RIPPLE		87mV RMS Max	
CURRENT REGULATION AT 100A LIMIT		+4.3A, -0.8A	
OUTPUT IMPEDANCE (see Figure 24)	DC TO 2kHZ	10mΩ OR LESS	
	2kHz TO 500kHz	300mΩ OR LESS	
EFFICIENCY AT (eo = 24VDC) (see Figure 23)	I_o = 20A	84.0%	
	I_o = 40A	84.2%	
	I_o = 60A	84.3%	
	I_o = 80A	84.3%	
	I_o = 100A	84.2%	
STANDBY LOSSES	I_{out} = 0A	APPROX 12W	
ACOUSTIC NOISE (see Table XIV)		36db MAX AT 8kHz	

*At the end of a 25 ft. Power Cable.

2.0 DESIGN PHILOSOPHY AND THEORY OF OPERATION.

The theory of operation of the AC-DC Power Processor is presented and includes the following functions:

- Series LC Resonant Inverter Power Stage.
- Control System.
- System Waveforms.

A discussion is also presented on component considerations and their relative impact on the AC-DC Power Processor.

a. SERIES LC RESONANT INVERTER POWER STAGE

The Series LC Resonant Inverter has been under development at TRW DSSG since 1969 under both NASA and U.S. Army contracts. The major design constraint for the Series Resonant Inverter is the method of energy control for the series resonant capacitor. Different techniques have been developed that optimize the power stage efficiency over the expected changes in the input power bus voltage.

As a switching device, the thyristor suffers from limitations in di/dt and dv/dt capabilities, reverse bias requirements for controlled turn-off and from relatively slow switching speeds. These shortcomings are circumvented in a very efficient manner in the series inverter circuit configuration.

Figure 1 illustrates the basic series inverter circuit used in this power supply. It consists of two SCR switches, a series resonant LC network (L1, L2, C1 and C2), output transformer T, output diodes CR1 and CR2 and output filter capacitor Co.

When a controlled rectifier is turned-on, an oscillatory current flows through the series combination of the inductor L, the load transformer T, and the series capacitor C. The sinusoidal current flow, occurring at a frequency determined by the LC components, is zero when an SCR is initially turned on, builds up to a maximum determined by the circuit parameters and then returns to zero. As the current passes through zero, the resonant capacitor is charged to a voltage higher than the supply voltage and

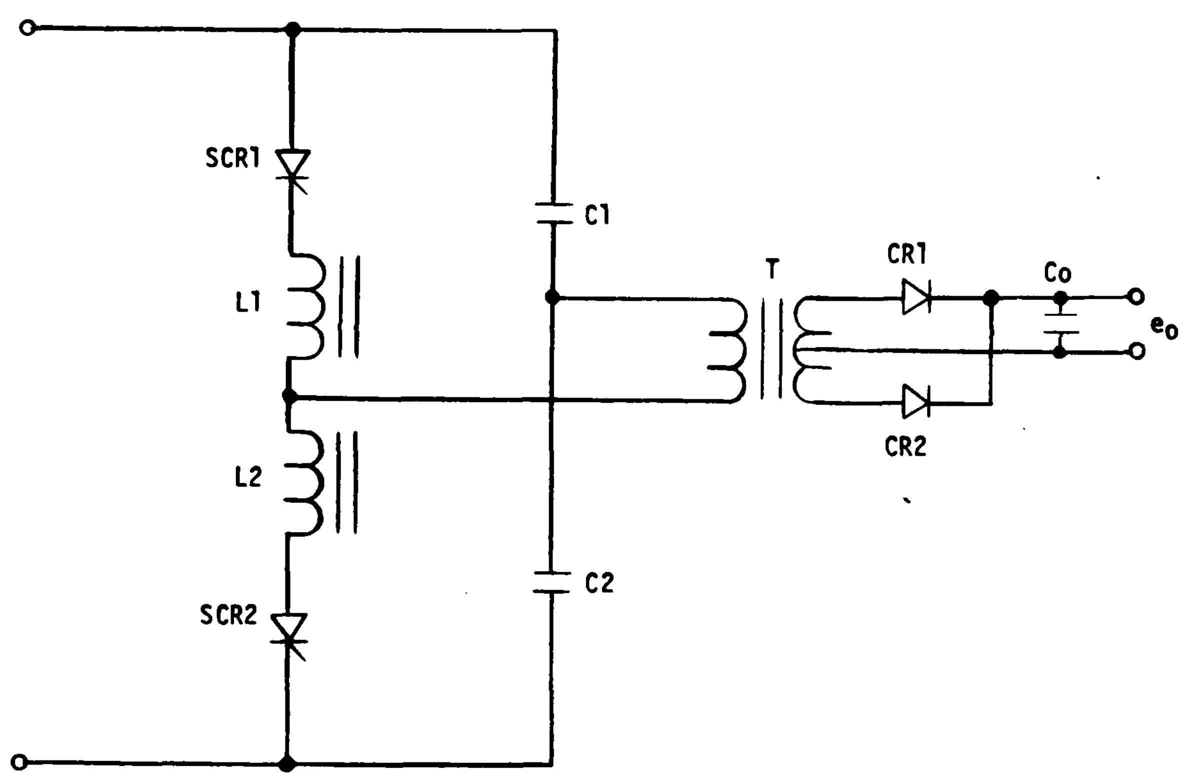


FIGURE 1 BASIC SERIES RESONANT INVERTER POWER STAGE

the inductor voltage drops to zero. The sum of the capacitor voltage and transformer voltage appears as a reverse voltage on the conducting SCR during its recovery to a blocking state.

The sinewave current ensures SCR operation below the maximum di/dt rating and minimizes the voltage-current product during the initial switching interval to mitigate the disadvantage of slow SCR switching.

Although the series inverter allows full utilization of the high-voltage and high-current capabilities of the SCR, it has an inherent functional subtlety requiring circuit modification.

For certain conditions of input line voltage and output load, the voltage across the series resonant capacitors will build up indefinitely until limited by dissipative inverter elements.

Clearly, in order to avoid excessive voltage build-up across C, a means must be implemented to control the energy build-up in the LC tank circuit.

A technique for protecting against voltage build-up is shown in Figure 2. The components CR3, CR4, and the secondary windings of L1 and L2 provide this capability. Excess energy, manifested as an induced voltage on the secondary winding of L1 and L2 during their respective discharge cycles, is fed into the output filter capacitor Co and the load, clamping the inductor L1 or L2 voltage to the output DC level. The excess energy is thus delivered to the output filter and output load at a constant di/dt rate depending on the DC output voltage and inductance L1 or L2. At the end of the so-called "spillover" period, capacitors C1 and C2 are charged to a value as to yield a constant series resonant inverter current, cycle to cycle.

The series inductor reverses its voltage at the peak current and continues as a cosine function until the winding N2 of inductors L1 or L2 is clamped to the output voltage through diodes CR3 or CR4. At this time, the energy stored in the inductor is transferred directly to the load from the inductor and the transformer and SCR current goes to zero, as shown in Figure 3.a., b and c. Due to the leakage inductance between the windings N1 and N2 of the inductor, it takes approximately 5μs before all of the inductor primary current is transferred to the inductor winding N2.

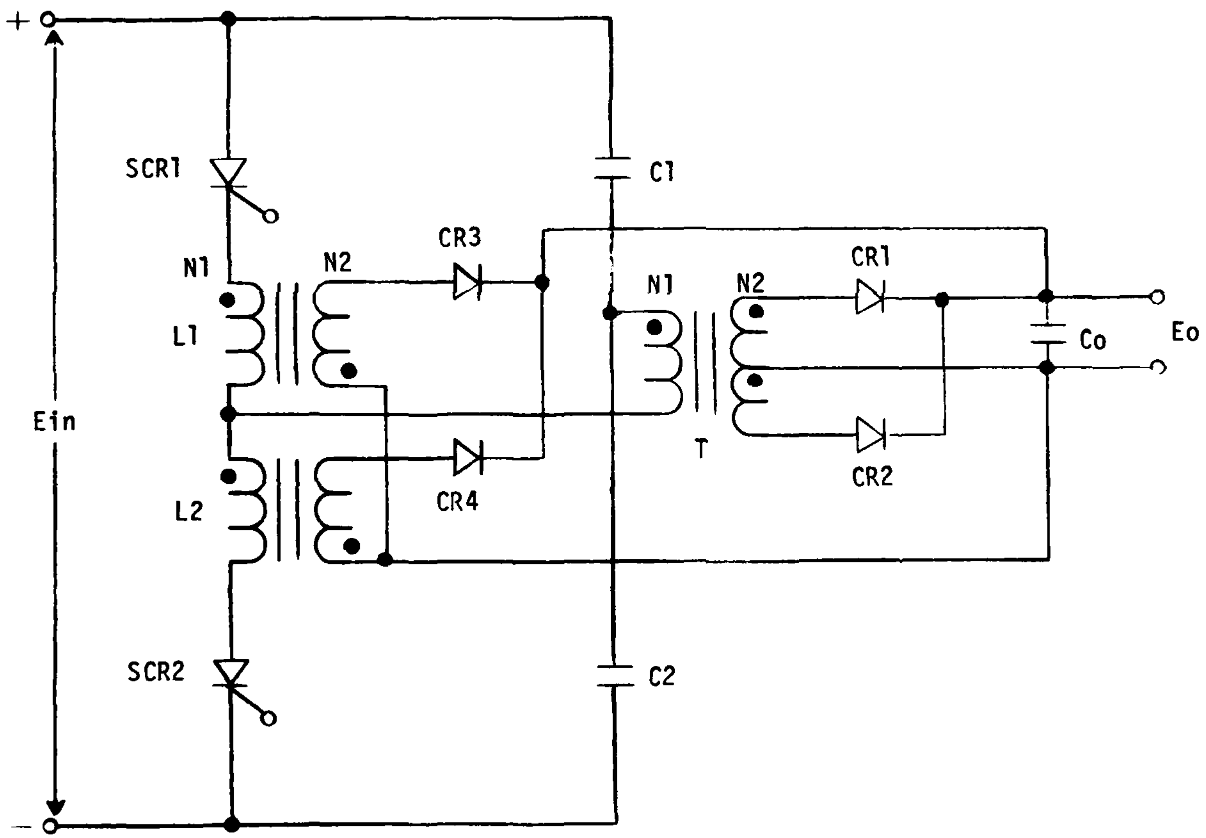
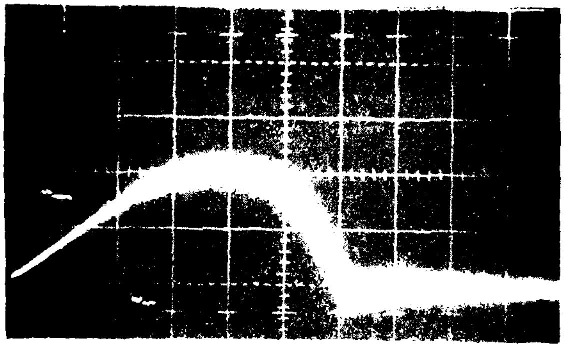
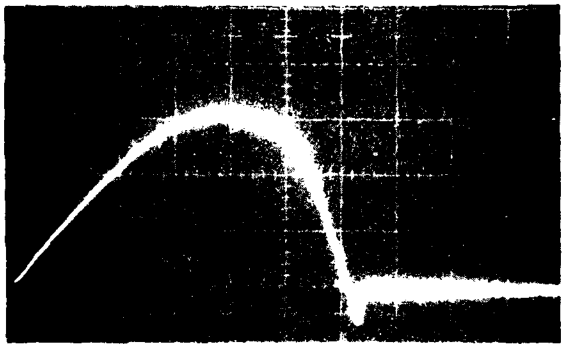


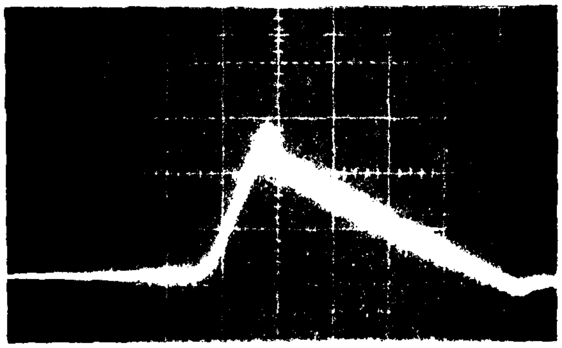
FIGURE 2 SERIES RESONANT INVERTER POWER STAGE WITH INDUCTOR ENERGY CONTROL NETWORK



a) Transformer
Primary Current
I = 20A/Div
Horiz = 5μs/Div



b) Transformer
Secondary Current
I = 40A/Div
Horiz = 5μs/Div



c) Inductor
Secondary Current
I = 40A/Div
Horiz = 5μs/Div

FIGURE 3 SERIES RESONANT INVERTER WAVEFORM

Figure 4 shows the instantaneous component voltage polarities when current starts flowing in inductor secondary winding N2.

The following voltage condition exists when inductor winding N2 starts to carry:

Assume: e_o

Transformer Secondary Voltage: $E_{T_{N2}} = 29V$ (Assume 1V diode drop) $= (E_o + E_{Diode})$

Transformer Primary Voltage: $E_{T_{N1}} = 29V \times \frac{29T}{9T} = 93.4V = E_{TN2} \times \frac{N1}{N2}$

Inductor Secondary Voltage: $E_{L2_{N2}} = 29V = E_o + E_{Diode}$

Inductor Primary Voltage: $E_{L2_{N1}} = 29V \times \frac{30T}{8T} = 108.75V = E_{L2_{N2}} \left(\frac{N1}{N2}\right)$

Assume: $E_{IN_{DC}} = 280V$

The instantaneous voltage loop equation is: (See Figure 4)

$$E_{IN_{DC}} + E_{L2_{N1}} - E_{T_{N1}} - E_{C2} = 0$$

$$280 + 108.75 - 93.4 - E_{C2} = 0$$

Capacitor Voltage: $E_{C2} = 295.35$

Thyristor Voltage: $E_{SCR1} = 295.35 - 280 = 15.35V$ Reverse Voltage.

During the 5μs inductor transfer time (See Figure 3.C.), the series capacitor continues to change voltage due to continued current flow in the inductor primary winding.

The net voltage change $\Delta E_{C2} = \frac{iT}{C2} = \frac{9A \times 5 \times 10^{-6}}{.72 \times 10^{-6}} = 62.5$ (Data from Figure 3.C.)

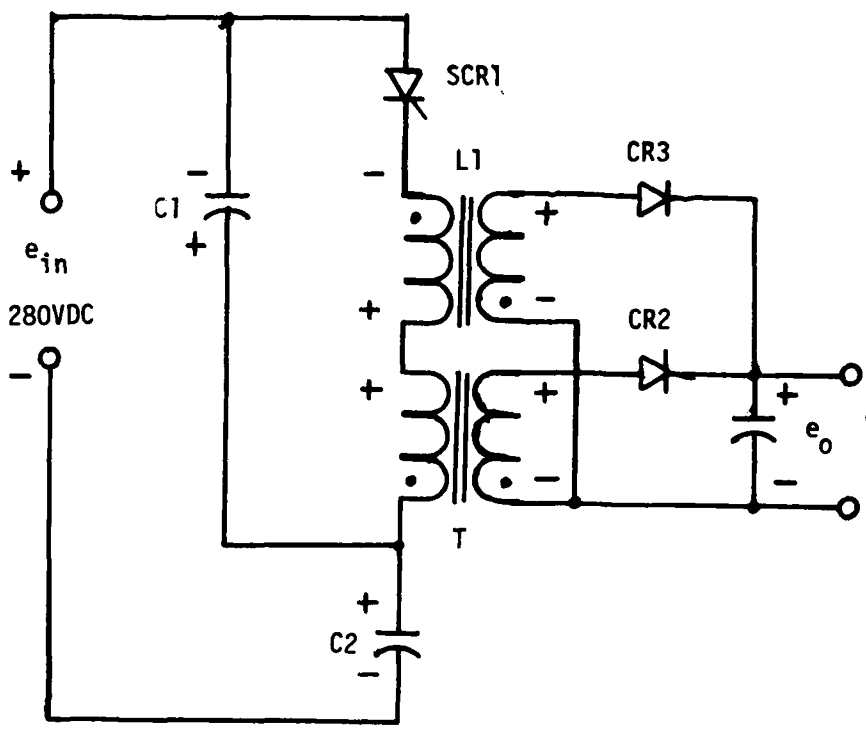


FIGURE 4 EQUIVALENT CIRCUIT DURING TURN-OFF OF SCR 1

The net reverse SCR voltage at turn-off is:

$$15.35 + 62.5 = 77.85\text{VDC}$$

During short circuit operation, the net reverse SCR voltage at turn-off calculates in a similar fashion to be 105VDC.

This demonstrates during all modes of operation that SCR always has reverse back biasing voltage to ensure SCR turn-off and that the reverse voltage is always under control using the new energy control technique where the secondary winding of the resonant inductor is clamped to the output filter capacitor.

b. Control System

Figure 5 presents a simplified control system block diagram for the AC-DC Power Processor. The block diagram includes a three phase input rectifier-filter network which feeds unregulated DC power to four phase displaced series resonant inverter power stages described in the previous section. The output power from the power stages is filtered by a common output filter capacitor.

The feedback voltage control system includes an output voltage divider. The divider voltage is compared to a precision reference voltage and the net error is amplified by an integrating operational amplifier. A current sensor (energy sensor) is located in series with the output filter capacitor and senses the output filter current change which is also amplified by the integrating amplifier. Output filter energy change transients are sensed immediately and controls the output voltage of the integrating amplifier.

The voltage to frequency oscillator converts an input analog voltage to a proportional digital pulse output frequency.

The input voltage to the voltage to frequency oscillator controls the oscillator output pulse frequency. The ring counter divides down the frequency and steers the pulse to free each power stage thyristor (SCR) in the correct sequence.

During output short circuit or overload operation, the current feedback mode becomes operational. The operating current level in one power stage is sensed and compared to a reference voltage. The operational amplifier output voltage is or-gated to the voltage-to-frequency oscillator and takes over control of the power stage operation.

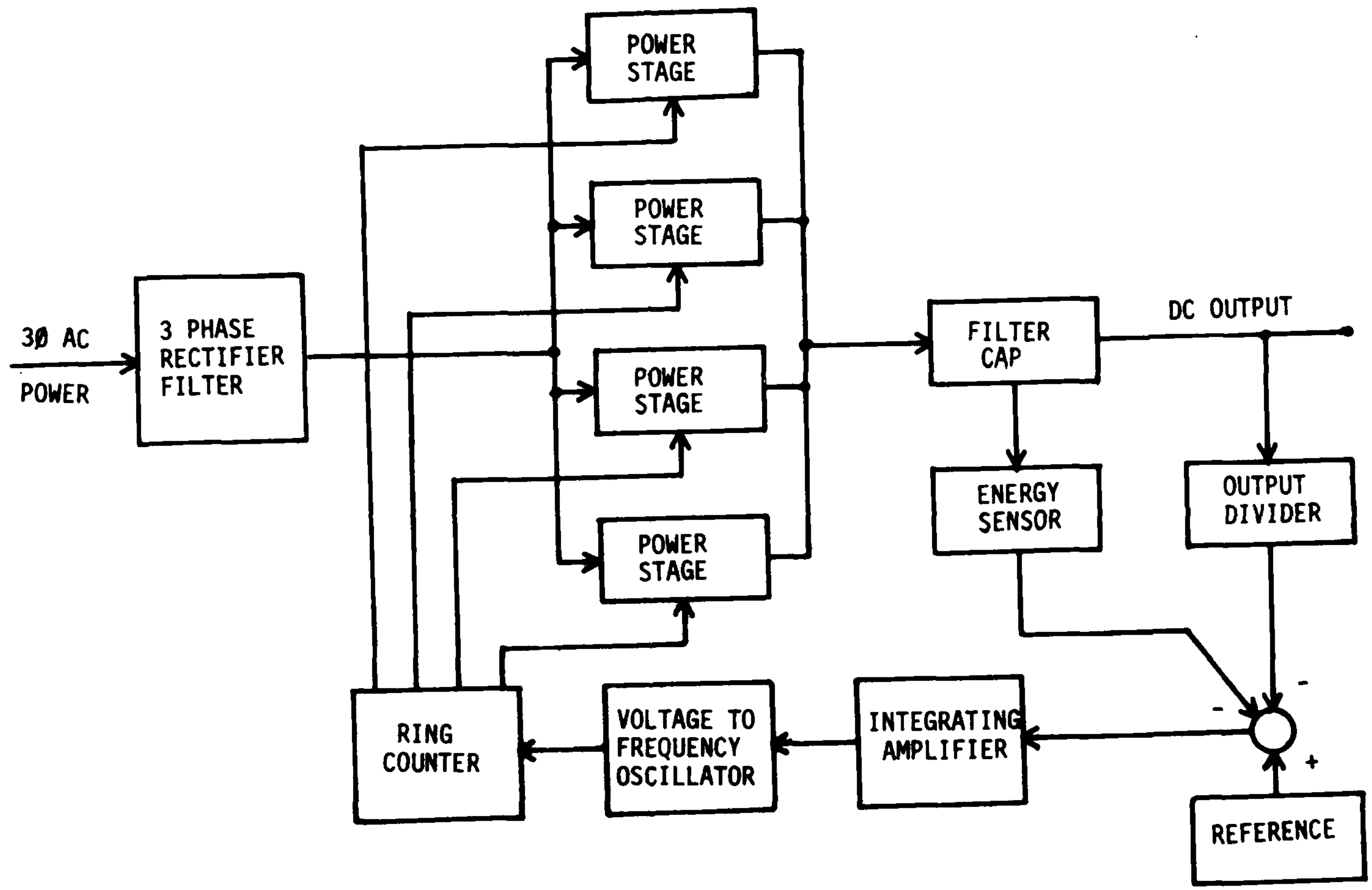


FIGURE 5   CONTROL SYSTEM BLOCK DIAGRAM

c. System Waveforms.

Figure 6 shows the control system waveforms which includes the integrator amplifier output voltages, the voltage to frequency oscillator output and the drive signals to the power stage SCR's.

At full load operation the voltage to frequency oscillator has its maximum input and maximum output frequency of 80kHertz which allows each power stage to operate at its 10kHertz maximum operational frequency.

Because of the phase displacement of the power stage, the effective output ripple frequency is 80kHertz and, therefore, minimizes the output filtering requirements.

As output load is decreased, the integrator amplifier output voltage decreases. This also decreases the output oscillator frequency to maintain the output power demand.

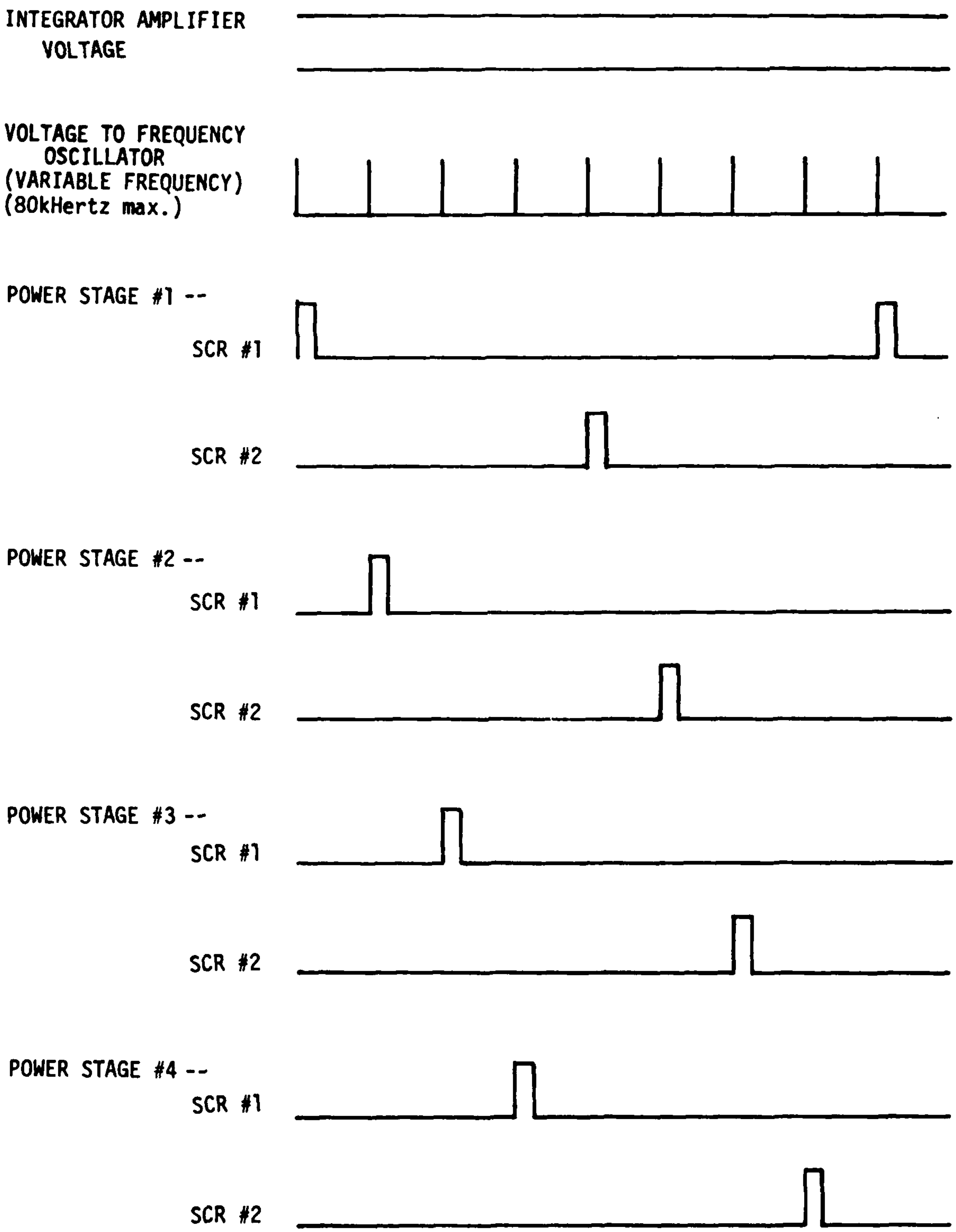


FIGURE 6 - CONTROL SYSTEM WAVEFORMS

d. Component Considerations

The component selection for the AC-DC Power Processor was governed by four basic requirements:

- Thermal control of Advanced Development Model using free convection cooling only.
- Electromagnetic Interference Control.
- Use of standard production power electronic parts to reduce production costs.

The Advanced Development Model is cooled by free convection cooling and has a specification to maintain the front panel at a maximum temperature of $110^{o}F$ in an ambient temperature of $77^{o}F$.

The driving force on the front panel temperature was that the power component operating temperature forced more heat load into the internal trapped air when the component thermal resistance was high between the component and the finned heat sinks. Every attempt was made to select electrical components that had low thermal resistance.

Because of this constraint for low thermal resistance, the power semiconductors and magnetics are oversized which penalizes the electrical component weight. The oversized components includes the input three phase bridge rectifiers, the power stage rectifiers and power magnetics.

Due to the advanced development nature of the thyristor series resonant inverters, power ac resonant capacitors are not available with different ac current ratings and therefore oversized components are also used.

Standard production electronic components are used throughout the design to minimize the component qualification costs and to allow for a component second source supplier. The standard parts already have known failure rate data and would minimize the U.S. Army deport stocking requirements.

3.0 AC-DC POWER PROCESSOR ADVANCED DEVELOPMENT MODEL

A complete electrical breadboard has been designed, fabricated and tested. This electrical design was then packaged into an Advanced Development Model, shown in Figure 7. The front panel dimensions are 19 inch wide by 10.5 inch high. The main chassis dimensions are 17 inch width, 18.9 inch length and 10 inch high.

The AC-DC Power Processor is divided up into five separate modular subassemblies for ease in manufacturing, testing and maintainability.

The following sections present the Electrical, Mechanical and Thermal Design of the AC-DC Power Processor. All reliabilitv predition and a breakdown of the power loss and weight is presented.

a. Electrical Design.

a.1 Block Diagram

The block diagram of the AC-DC Power Processor is shown in Figure 8.

The 3 phase 120/208V, 50/60/400Hz input power passes through a high frequency EMI filter and AC input power circuit breaker. The AC power passes through a low frequency EMI filter and is then rectified by a full wave, three phase bridge and filtered.

The filtered DC Power (270VDC) is fed to four SCR series resonant inverter power stages, of which each is operating at a maximum frequency of 10kHz and is phase displaced with respect to each other to minimize the input and output filtering requirements. With four parallel operating stages, the peak AC current in the power components is reduced and minimizes the audio noise emanating from the unit. The four modules also help to distribute the heat loss through the mechanical package.

Each series resonant inverter powers a transformer and output rectifier and a common output filter. The DC output power goes through the DC output breaker and output EMI filter. This illustrates the power flow from the three phase AC input to the DC output for the AC to DC power processor.

The three phase AC input also supplies power to a fused three phase transformer rectifier-filter to establish the necessary voltages for all of the internal control logic power for the AC to DC power processor.

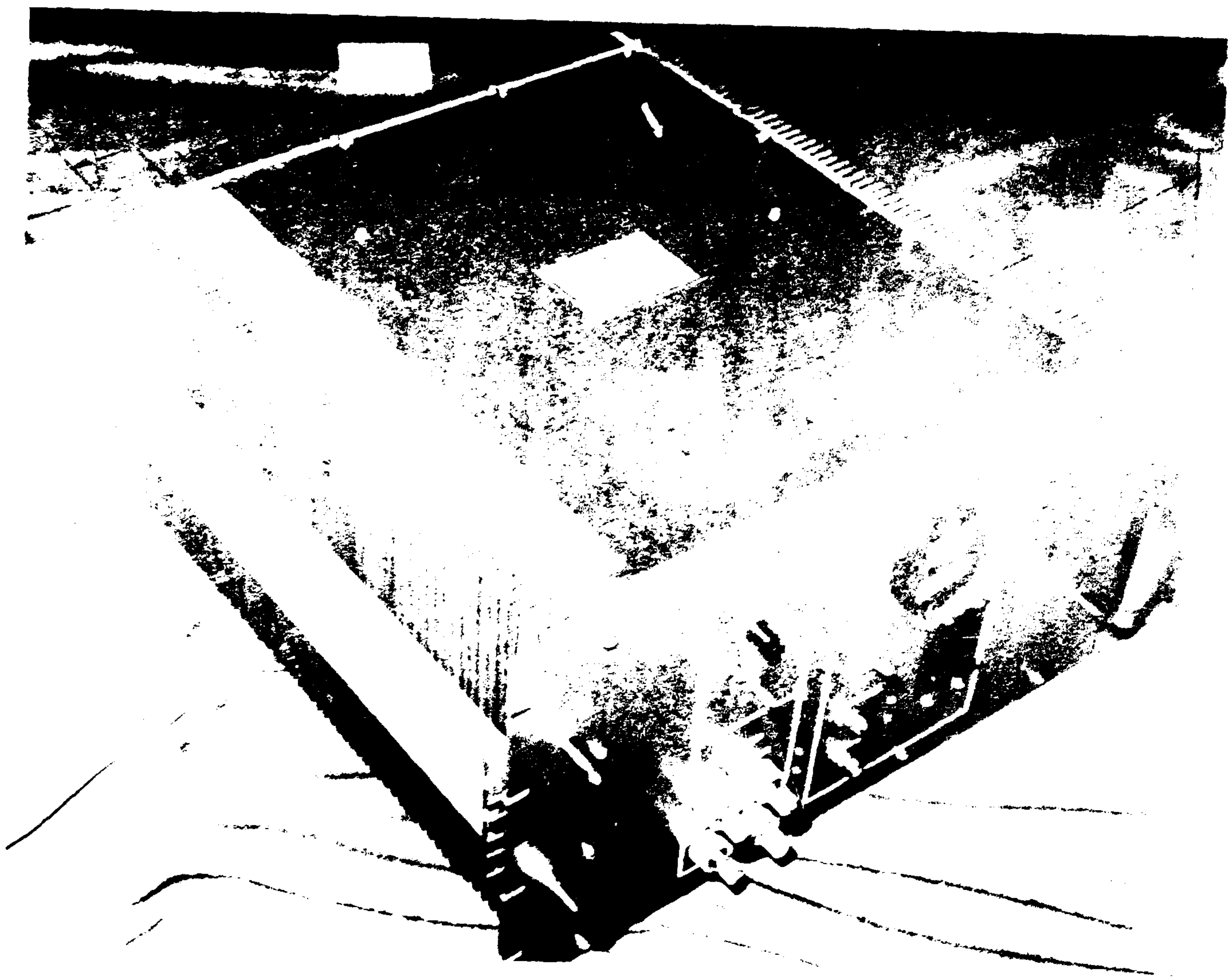
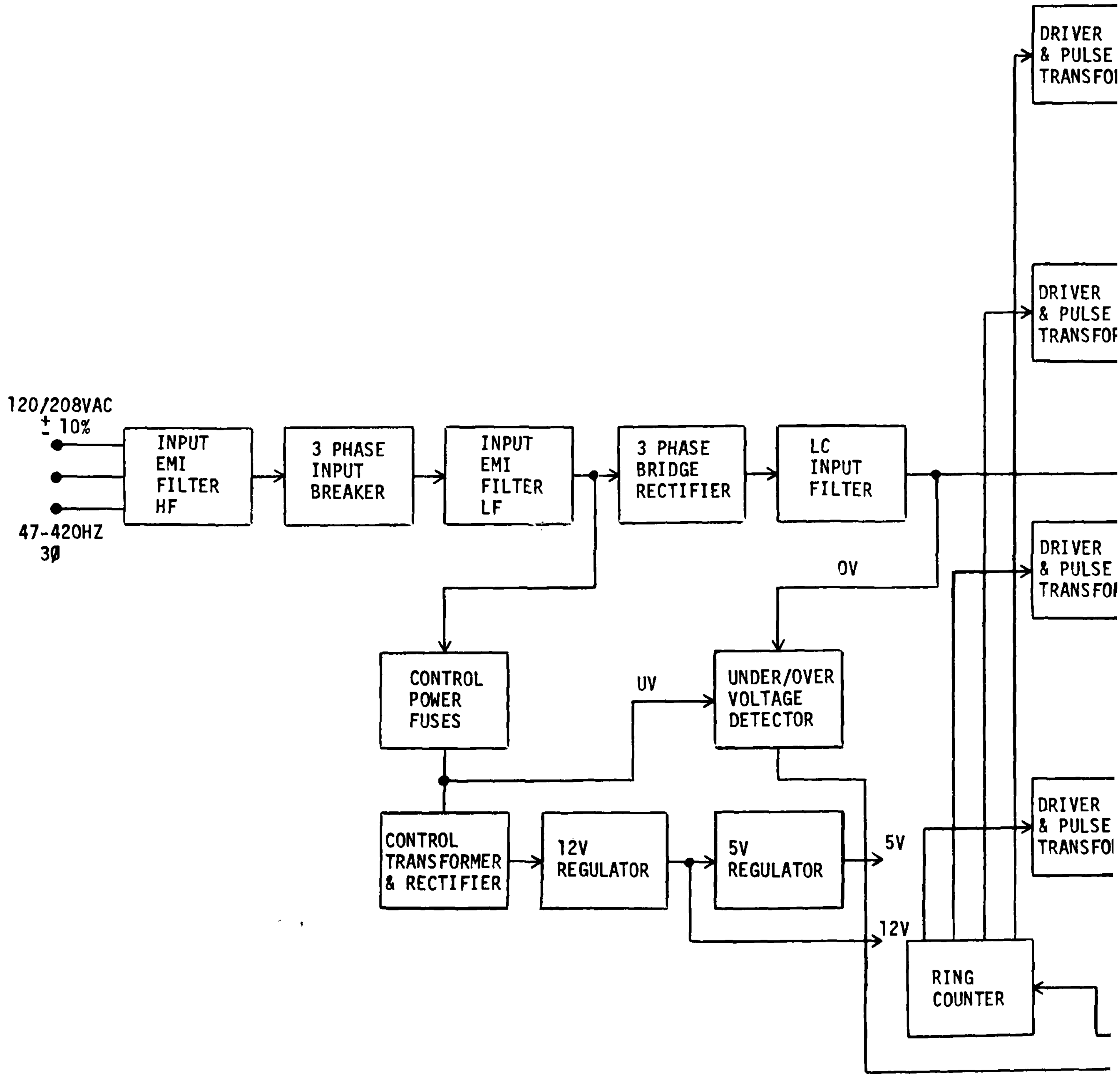


FIGURE 7 - ADVANCED DEVELOPMENT MODEL


120/208VAC
± 10%
47-420HZ
3Ø
INPUT EMI FILTER HF
3 PHASE INPUT BREAKER
INPUT EMI FILTER LF
3 PHASE BRIDGE RECTIFIER
LC INPUT FILTER
OV
CONTROL POWER FUSES
UV
UNDER/OVER VOLTAGE DETECTOR
CONTROL TRANSFORMER & RECTIFIER
12V REGULATOR
5V REGULATOR
5V
12V
RING COUNTER
DRIVER & PULSE
DRIVER & PULSE
DRIVER & PULSE
DRIVER & PULSE

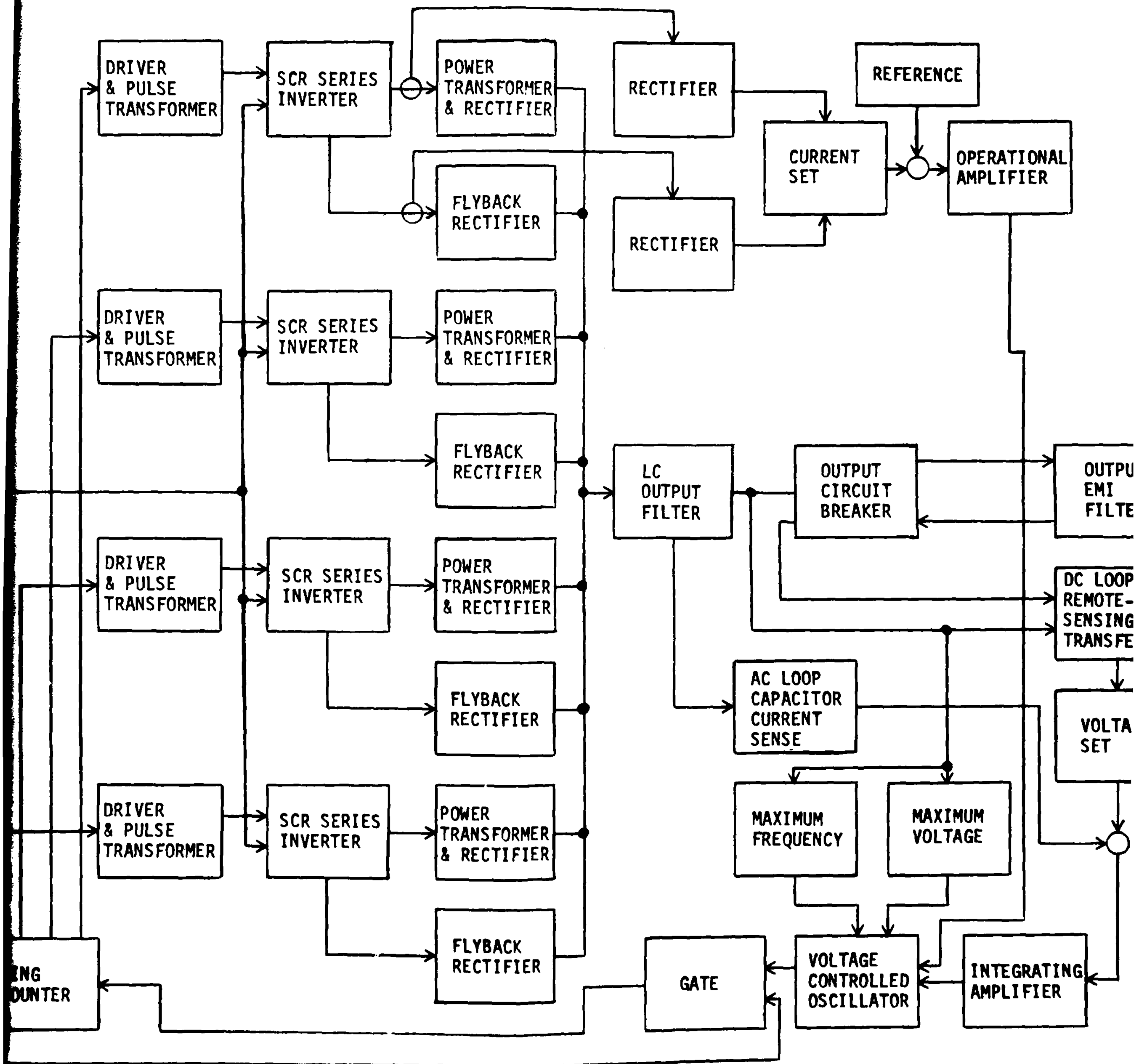


FIGURE 8 BLOCK DIAGRAM AC/DC POWER PROCESSOR

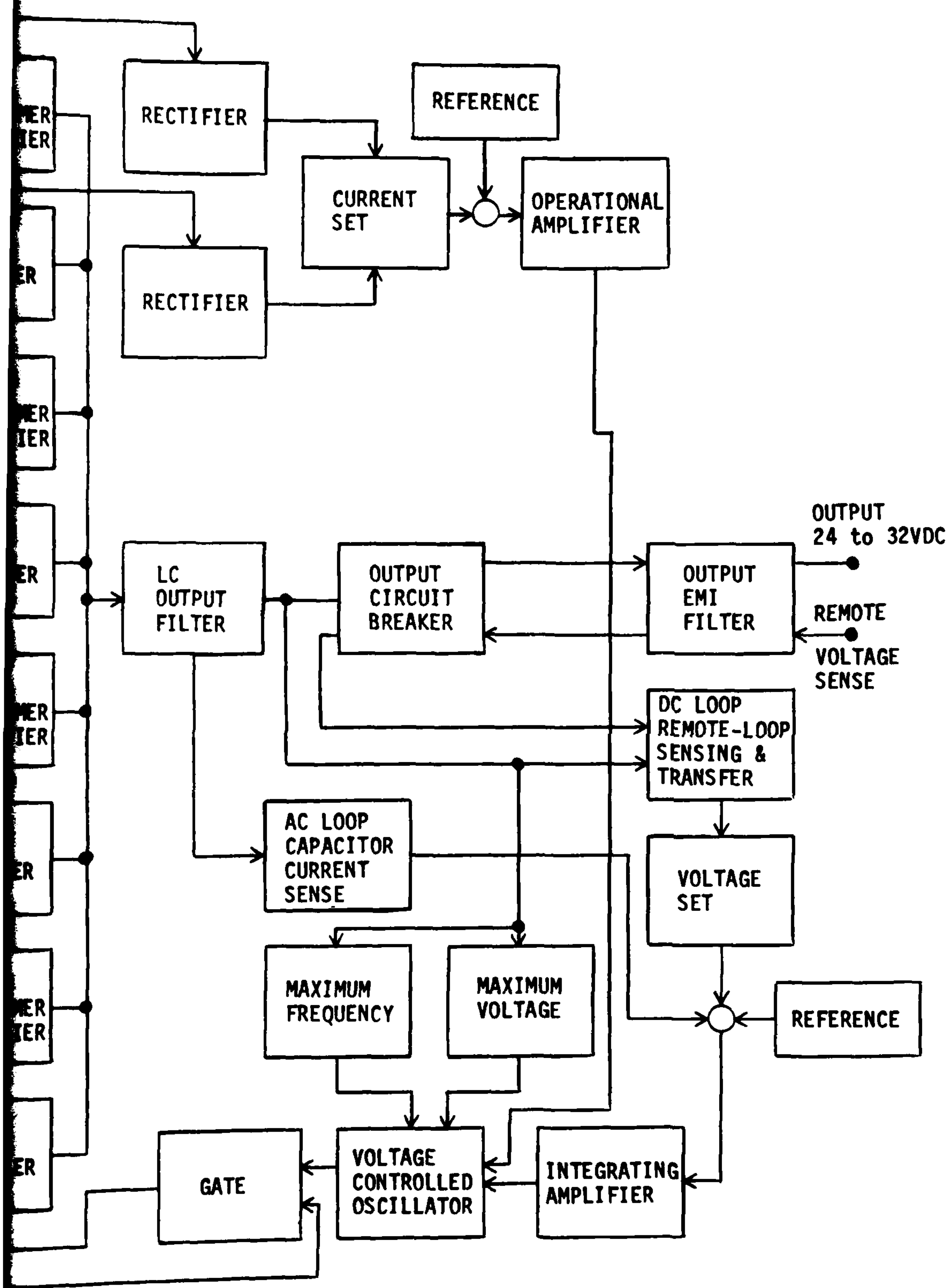


FIGURE 8 BLOCK DIAGRAM AC/DC POWER PROCESSOR

The undervoltage and overvoltage sensor monitors the input power bus voltage and provide automatic turn-off of the power processor during abnormal input power line conditions. When the input power bus returns to the normal operating range, the undervoltage/overvoltage sensor will allow the power processor to automatically return to its normal operating conditions. Undervoltage operation: (Off at 66 Volts (L-N), on at 108 Volts (L-N).) (Overvoltage operation: Off at 144 Volts (L-N) on at 132 V (L-N).)

Each SCR series resonant inverter has a SCR gate pulse transformer and an associated driver stage to control the relative firing of the power SCR's. The inverter control logic accepts the following signals and increments the ring counter which determines the correct firing sequence for each SCR.

1) Output voltage regulator signal to adjust each module to meet the required DC output voltage.

2) Output current regulator signal to adjust each module to meet the output current limit requirements.

3) Maximum frequency set to limit the maximum frequency of operation.

4) Maximum voltage clamp to limit the maximum output voltage during transients.

5) Undervoltage/overvoltage sensor to halt power processor operating in the event of abnormal input power bus condition.

The external voltage adjustment varies the DC voltage feedback signal for the voltage regulator. This feedback signal and the signal determining the output filter energy level is compared with a precision reference. The combination of the dual feedback loop is to provide high loop gain without instability and improved transient response due to input line voltage and output current disturbances.

The external current adjustment varies the current feedback signal for the current regulator and has a range of 5 amps to 100 amps. This feedback signal is compared with a precision reference. The net analog error is amplified by the current regulator electronics and provides the necessary signal to the inverter control logic.

The DC output voltage can be directly controlled from the output filter terminals of the power processor or from the remote sense lines at the end of the 25 ft. DC output power cable. The remote/local sense transfer network automatically transfers to an internal local sense if the output remote sense lines open or the output circuit breaker is tripped.

a.2 Schematic

Figures 9 through 12 contain the complete electrical schematic for the AC-DC Power Processor.

Figure 9 shows the schematic for the output LC filter, ASDTIC feedback current sensor (C19 & T1), output breakers (CB2), output EMI filter for both power and remote sense line; output current shunt (R4) and the front panel metering and adjustment for output voltage and output current.

Figure 10 shows the schematic for the four phase displaced series resonant power stage modules. Two modules are located on mechanical subassebmly A2 and the other two are located on mechanical subassembly A3.

DC input power comes in on point A & B and DC output power comes from points G & H (also shown on Figure 9).

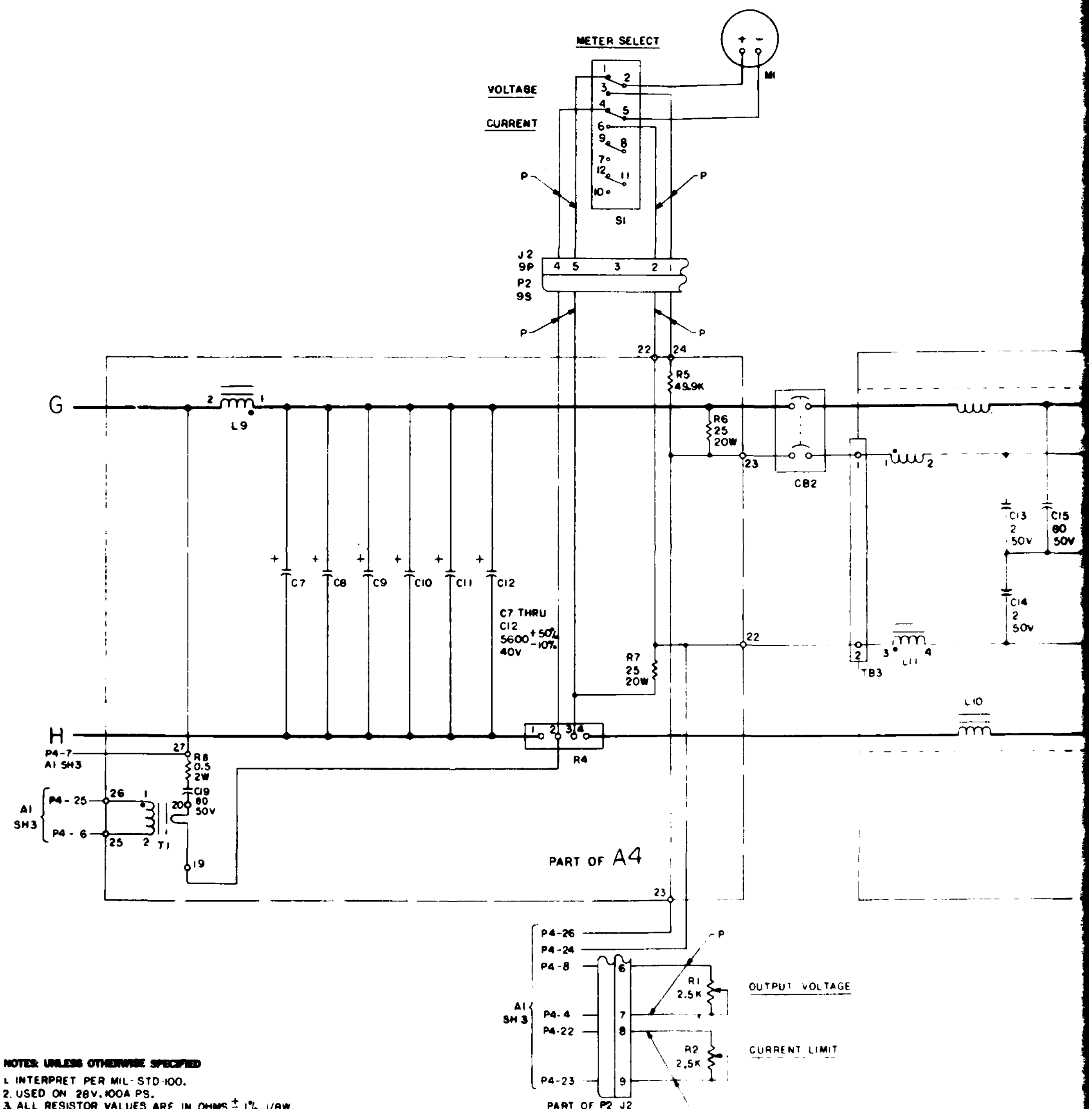
The following description is presented for one module and is similar for the remaining three modules.

The power module includes an input filter capacitor C1, two power thyristor VR1 and VR2 and their associated pulse transformers T1 and T2, series resonant inductor assembly L1 (contains two separate inductors), power transformer T3, output rectifiers (CR1 & CR2), series resonant capacitors C4 and C5 and output filter capacitor C6.

Only one module contains a current sensor for current regulation. One current sensor is included as part of L1 and the other current sensor is included as part of T3.

Each thyristor has a RC network for noise suppression on the gate and another RC network for dv/dt control.

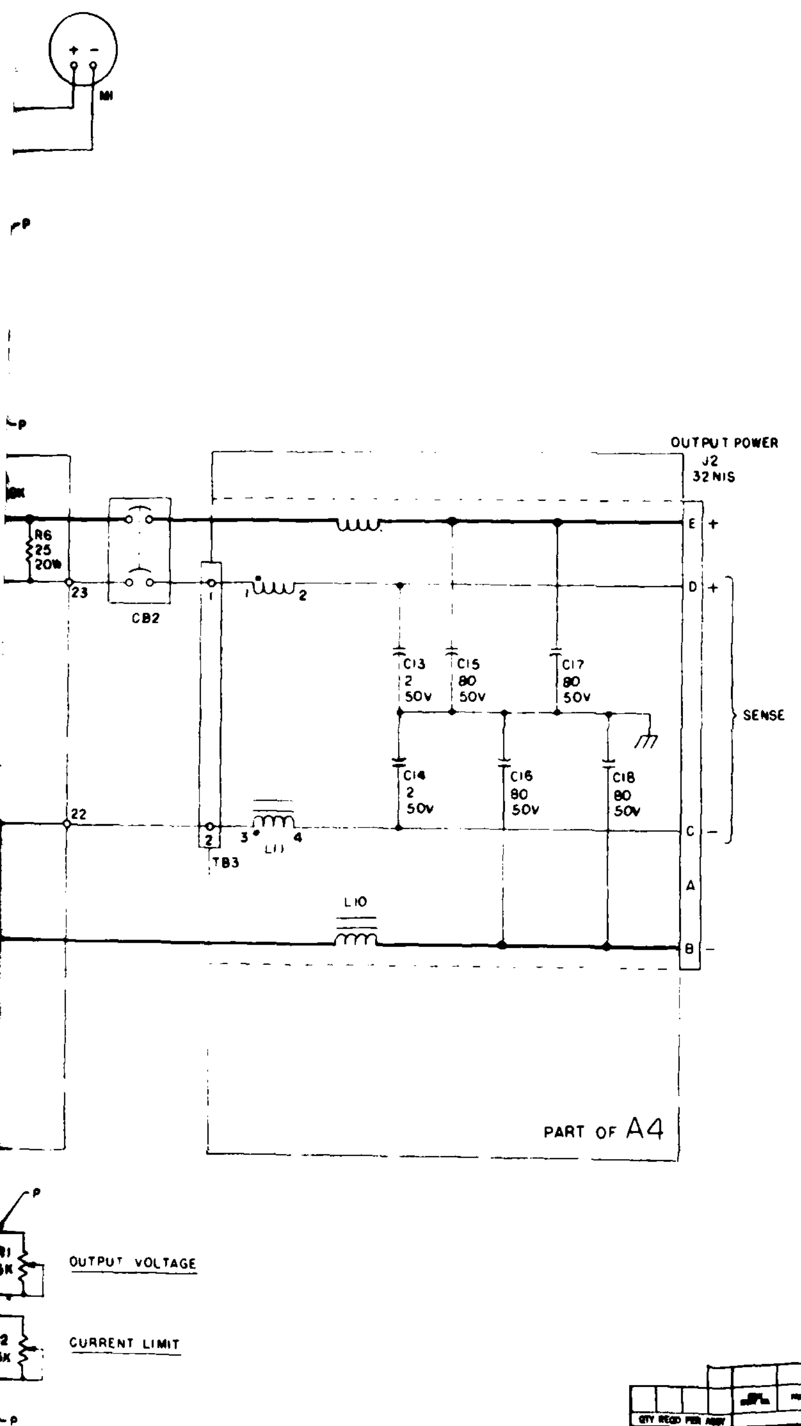
Figure 11 shows the schematic for output regulator control electronics.



NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET PER MIL-STD-100.
2. USED ON 28V, 100A PS.
3. ALL RESISTOR VALUES ARE IN OHMS ± 1%, 1/8W.
4. ALL CAPACITOR VALUES ARE IN MICROFARADS ± 10%.
5. REF DWG NO.: ASSY DWG 295048
   INTERCONNECTION DIAGRAM 295051
   WIRE LIST 295052

FIGURE 9 OUTPUT FILTER AND METERING



REFERENCE DESIGNATIONS		
	LAST USED	DELETED
	CB2 DS1 F4 J2 M1 R2 S1 TB1	
A1	AR1 C38 CR24 J2 R51 T1 U10 VR7	CR6 THRU 9
A2 & A3	C16 CR4 J1 L2 R8 T6 VR4	
A4	C19 CR1 FL3 J2 L11 P6 R8 TB3 VR2	

295050

ER AND METERING

28V,100AMPS 295048

DAAB07-76-C-0336

SCHEMATIC DIAGRAM
AC TO DC POWER
PROCESSOR

E 11982 295050

NONE

1 OF 4

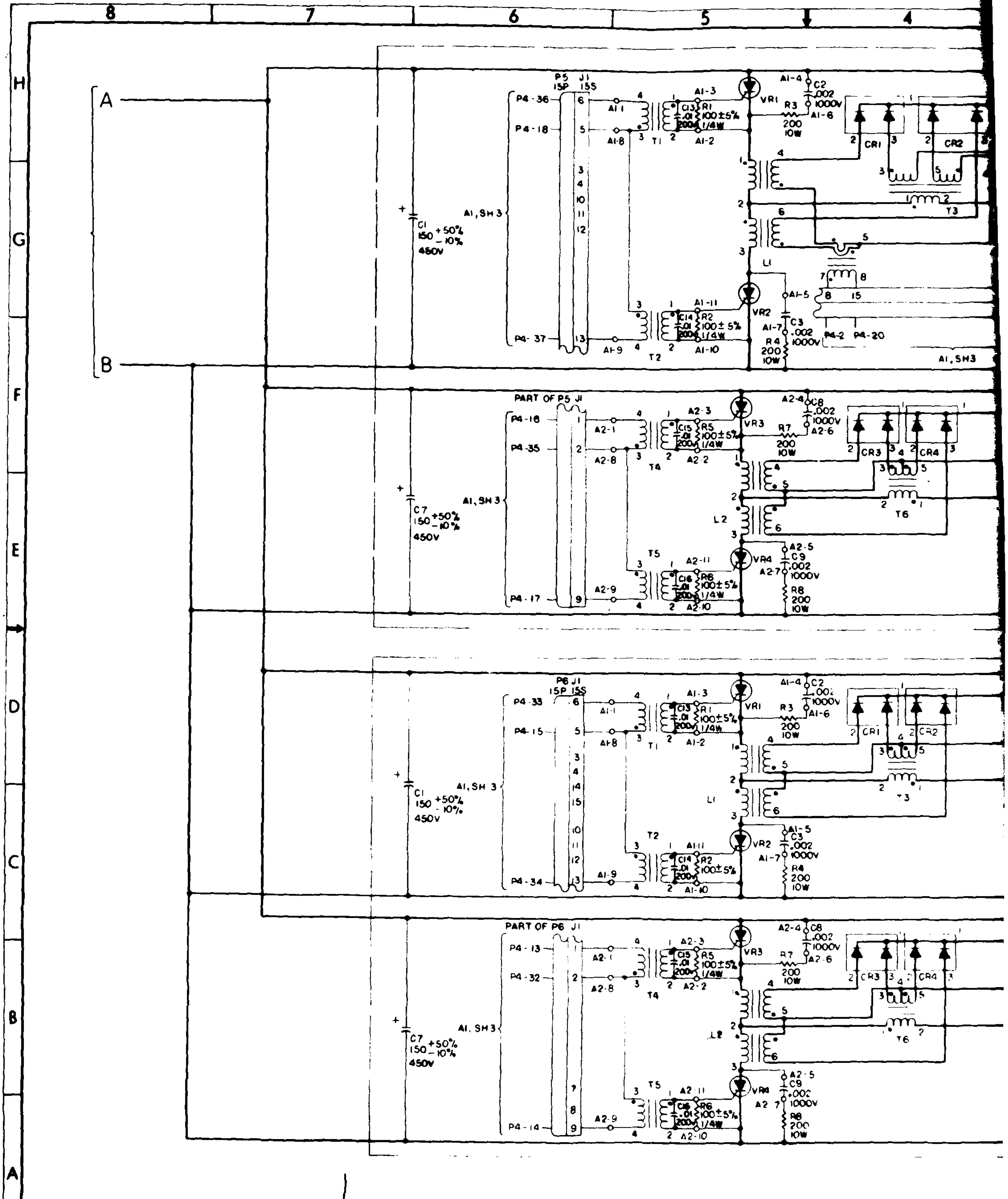


FIGURE 10 INVERTER POWER STAGE

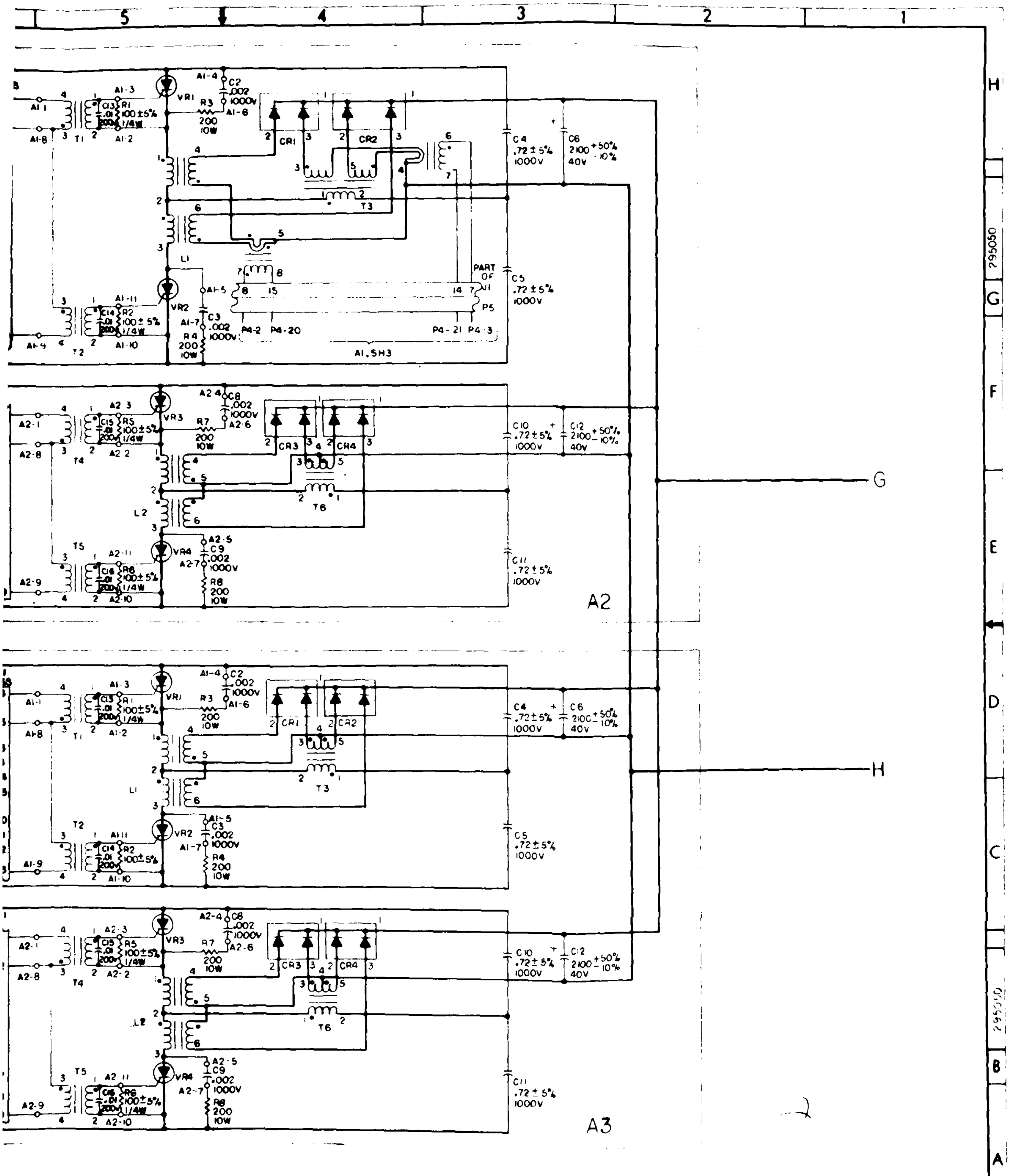


FIGURE 10 INVERTER POWER STAGE

E 11982 295050

NONE 2

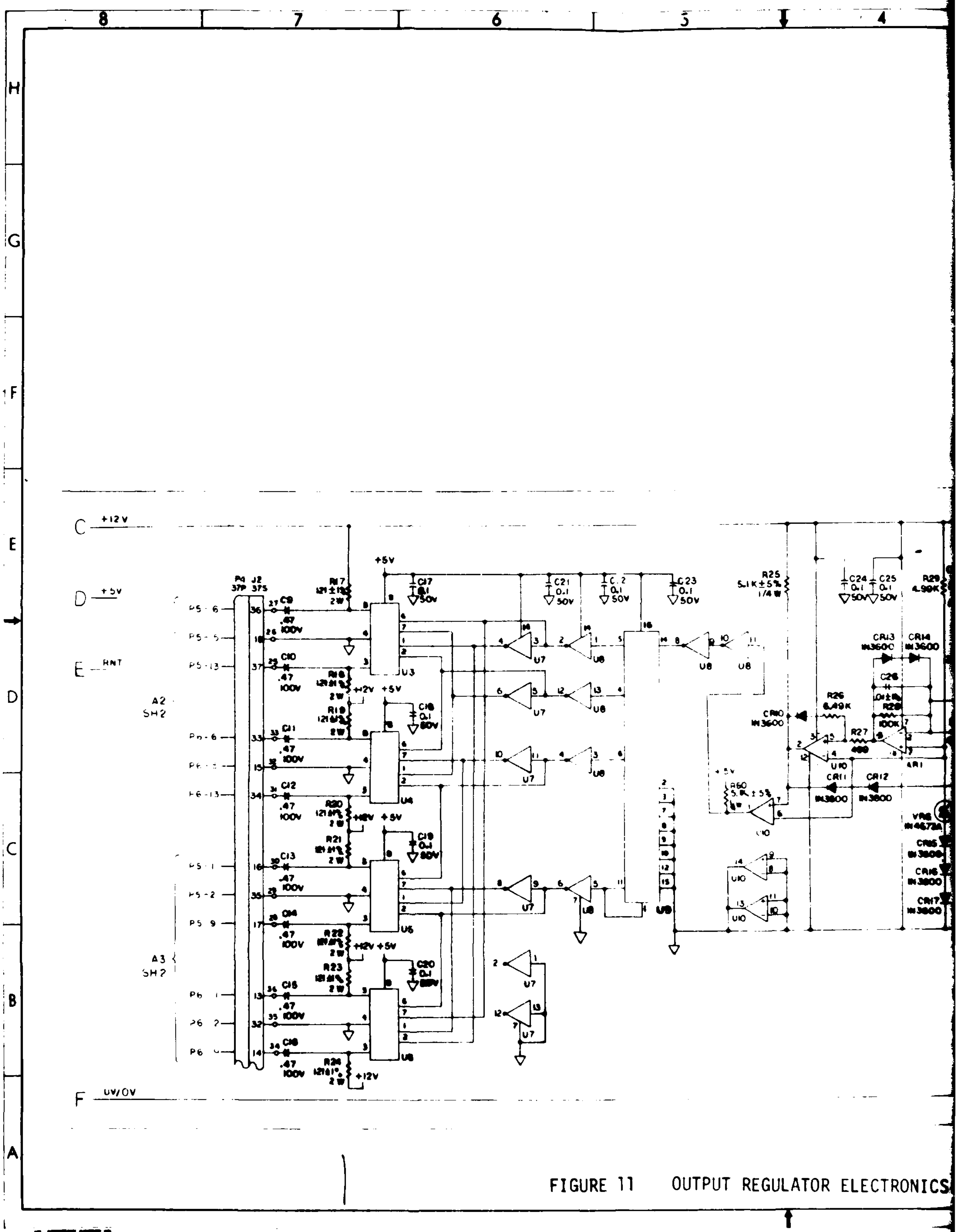


FIGURE 11 OUTPUT REGULATOR ELECTRONICS

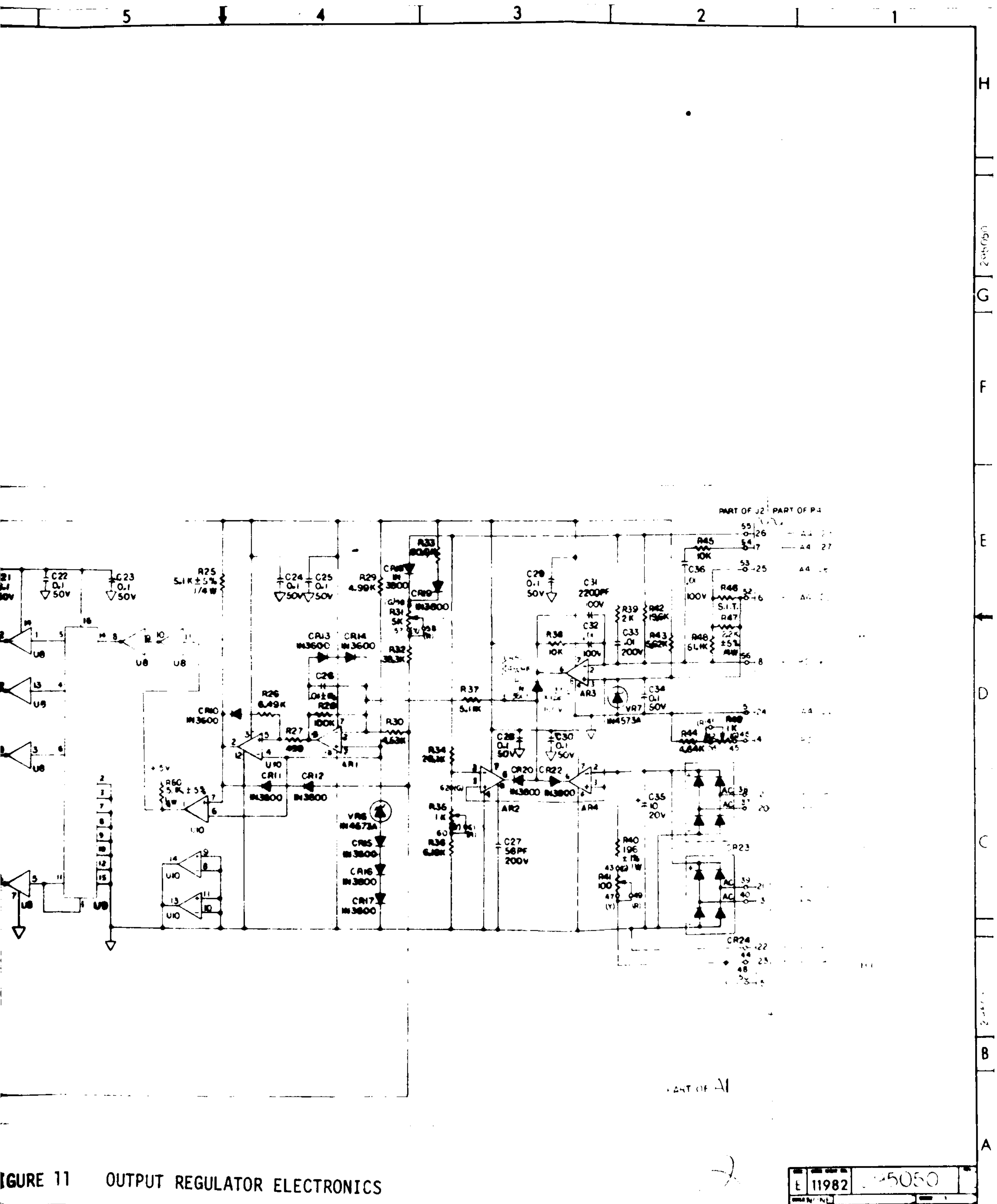


FIGURE 11 OUTPUT REGULATOR ELECTRONICS

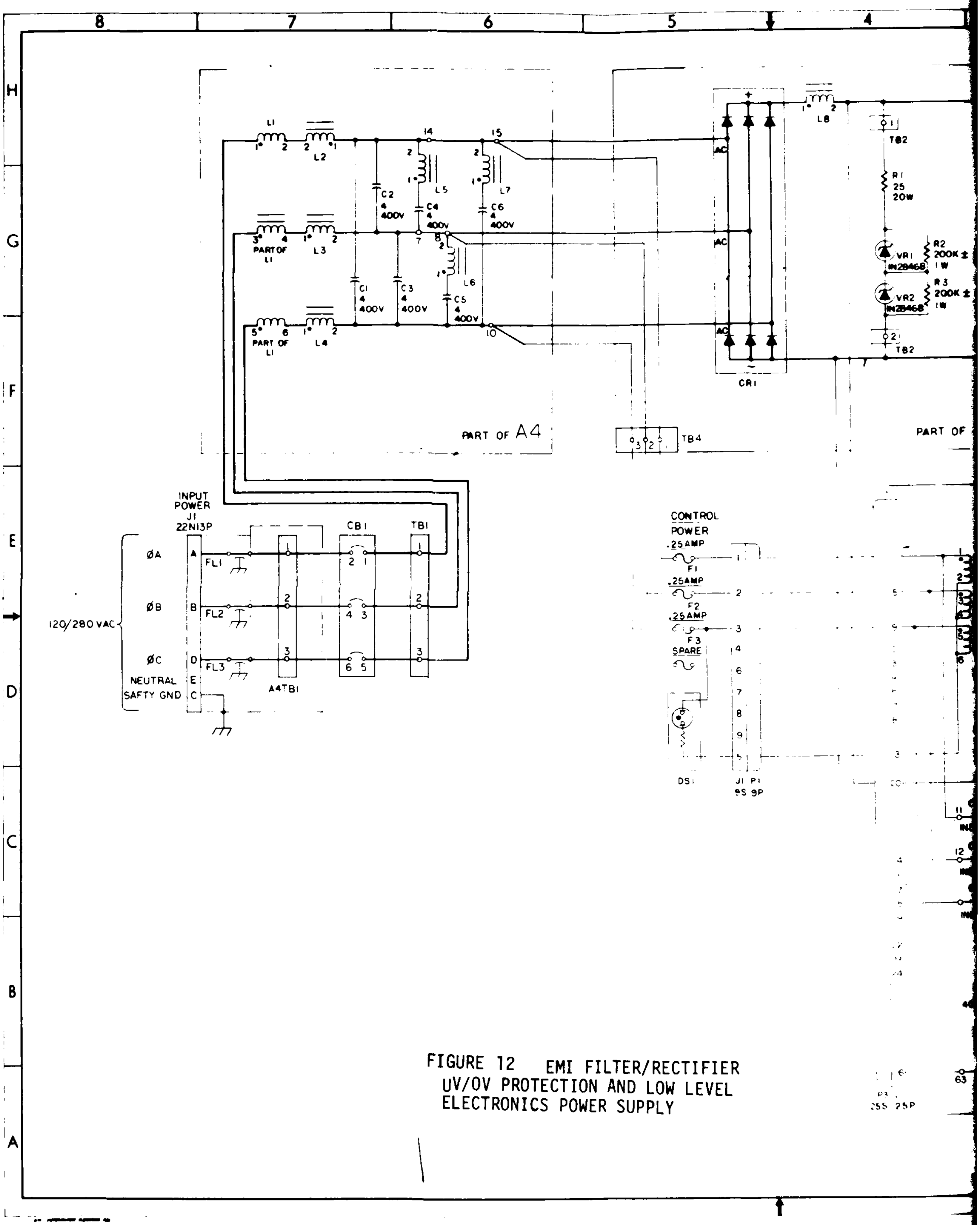
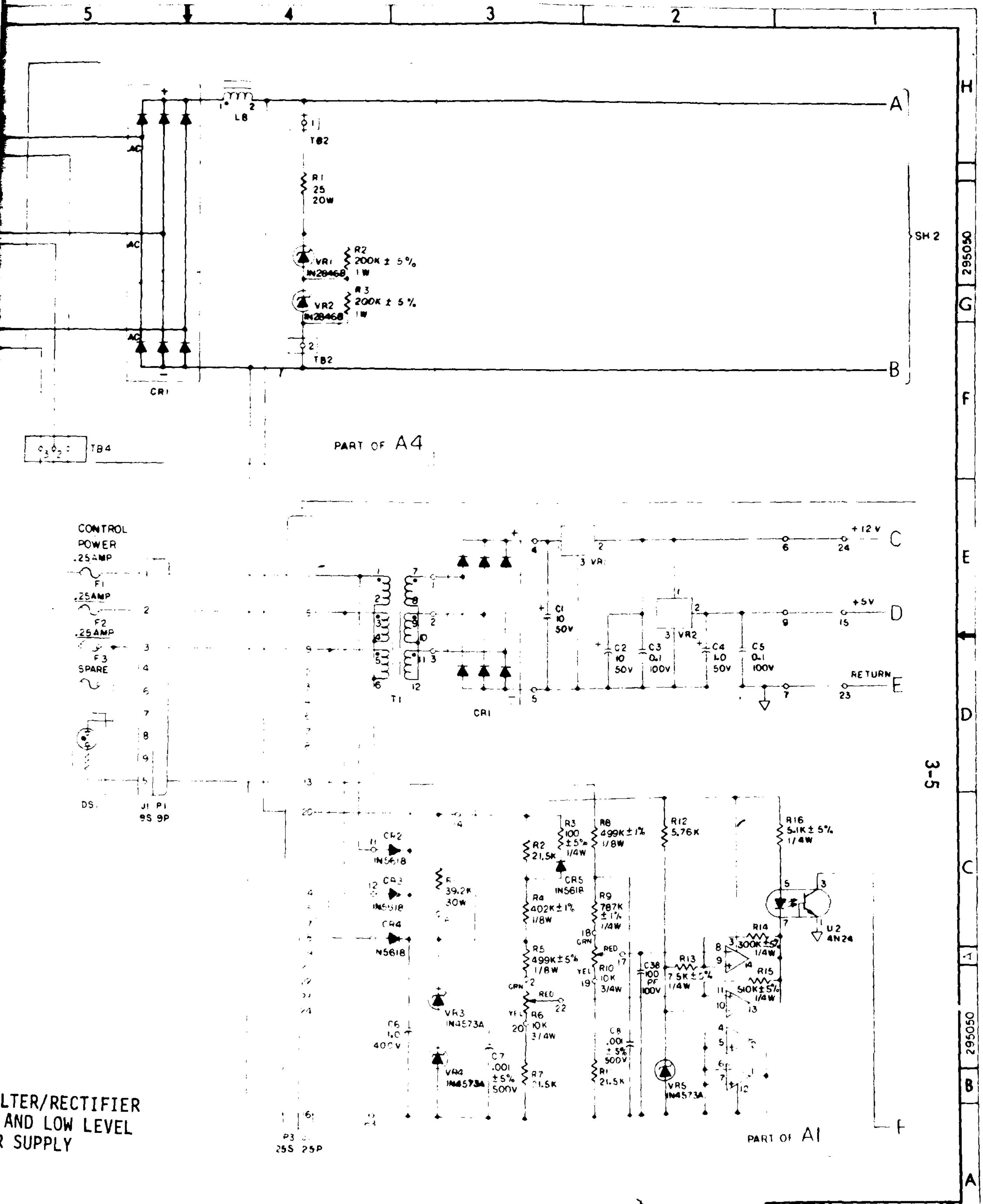


FIGURE 12 EMI FILTER/RECTIFIER UV/OV PROTECTION AND LOW LEVEL ELECTRONICS POWER SUPPLY



FILTER/RECTIFIER
)N AND LOW LEVEL
/ER SUPPLY

E 11982 295050

The input signal includes:

Point C	+12VDC Power
Point D	+5VDC Power
Point E	Return
Point F	UV/OV Signal

Output Voltage Sense and Adjustment

Output Current Sense and Adjustment

The output signals are 8 pulse drives to the series resonant power stages.

Operational amplifier AR3 provides the output voltage sensing. Resistor R49 controls the maximum output voltage setting.

Operational amplifier AR4 provides the output current sensing. Resistor R41 controls the maximum output current setting.

Operational amplifier AR2 provides the sensing for maximum output overvoltage during transients. Resistor R35 controls the maximum output overshooting setting.

These three operational amplifiers (AR2, AR3, and AR4) are diode or-gated (CR20, CR21, and CR22) to the voltage to frequency oscillator composed of operational amplifier AR1 and U10. The maximum frequency of the voltage to frequency oscillator is adjusted by Resistor R31.

The output from the voltage-to-frequency oscillator goes to the ring counter U9 and the output pulse drivers (U3, U4, U5 and U6).

Figure 12 shows the schematics of the input EMI filter, input rectifier, control power transformer and regulators and input undervoltage and overvoltage sensor.

The input signals are the 3 phase 120/208VAC 47Hz to 420Hz.

The output signals are:

- Points A & B rectified DC power to series resonant modules.
- +12V, +5V & Return for Control Electronics.
- OV/UV Signal to Control Electronics.

The high frequency EMI filters include FL1, FL2 and FL3. CB1 is the input three phase circuit breakers. Inductor L1 is the common mode EMI filter.

The low frequency EMI filter is composed of inductors L2 through L7 and capacitors C1 through C6.

Diode CR1 of A4 is the main three phase, full wave bridge rectifier. Inductor L8 is the power filter choke.

Power Zener Diodes (VR1 and VR2), part of A4, bleed power off the main DC bus during input overvoltage transients.

Three low current fuses (F1, F2 and F3) control the three phase power to transformer T1. The output of T1 is rectified by diode bridge CR1, part of A1. This DC power is regulated to +12V by VR1, part of A1 and to +5V by VR2, part of A1.

The main DC input power is regulated down to +12V by Zener Diodes (VR3 and VR4) for the undervoltage and overvoltage control electronics.

Amplifier U1 senses for undervoltage and overvoltage conditions and provides an output signal to the regulator control electronics through the optical isolator U2.

b. Mechanical Design

Figure 13 shows the AC-DC Power Processor in an open position with its handling fixture during electrical checkout. The mechanical subassemblies include:

- Front Panel
- A1 - Printed Circuit Board
- A2 - Left Side (2 Power modules)
- A3 - Right Side (2 Power modules)
- A4 - Rear Panel

The parts list for each mechanical subassembly is contained in Appendix A.

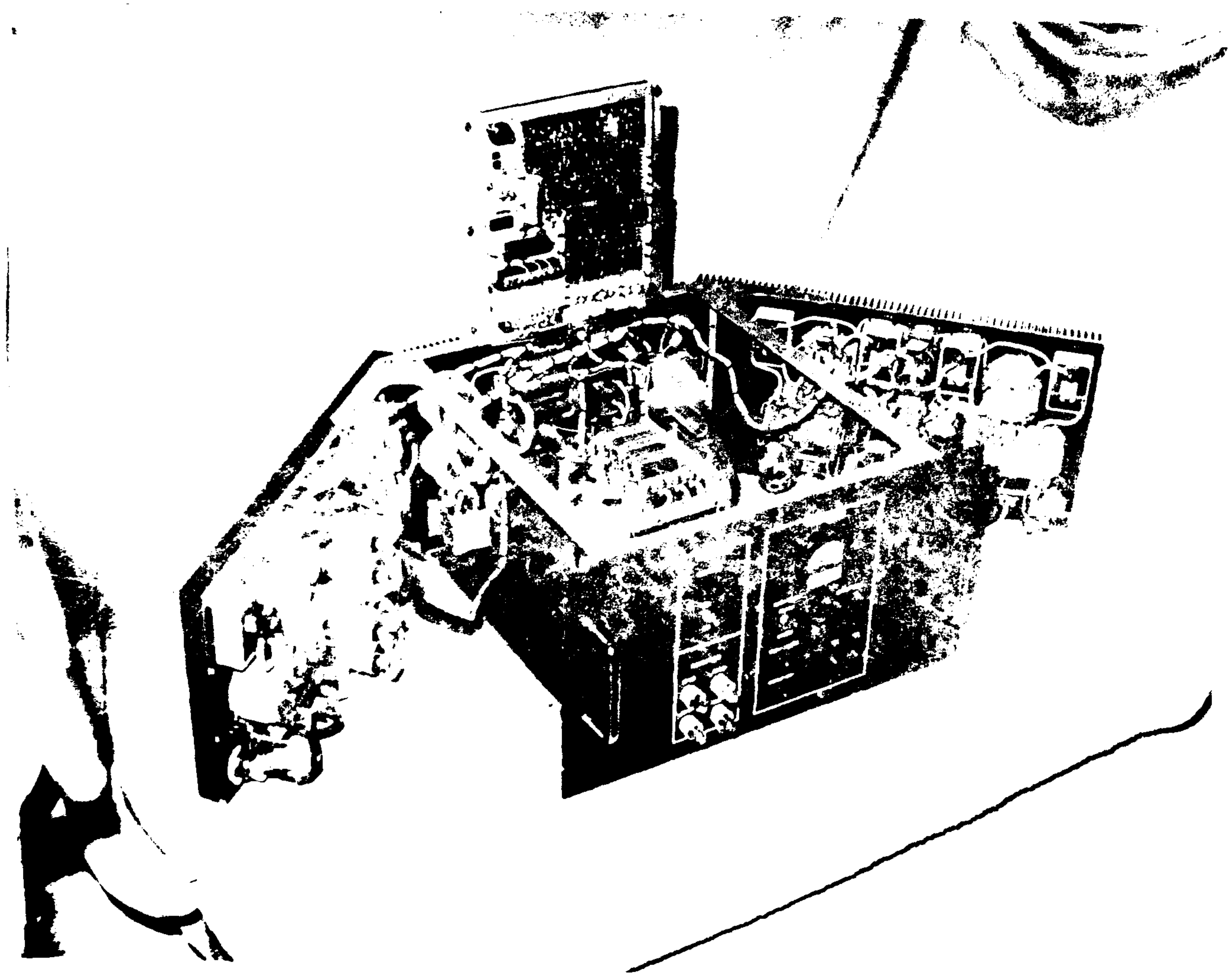


FIGURE 13 OPEN VIEW OF AC-DC POWER PROCESSOR

Figure 14 shows the Front Panel-Front View. Input power controls are on the left and output control are on the right.

Input control consists of

- Input 3 Ø Circuit Breakers
- Pcwer on Indicator LIght
- 3 Fuses Plus Spare for Control Power

The Output control consists of:

- Output DC Circuit Breaker
- DC Voltage/DC Current Meter
- Meter Select Switch
- Output Voltage Adjustment Pot
- Output Current Adjustment Pot

Figure 15 shows rear view of the front panel. It shows wiring of components and location of subassembly connectors: TB1 (3 Ø power connection) J1 (3 Ø control power connection), J2 (DC control signal) and CB2 (DC power and remote sense).

The interface between the front panel and the side panels has a machined surface in order to increase the thermal resistance of the front panel and to allow it to run cooler than the remainder of the mechanical assembly.

Figure 16 shows the printed circuit board assembly (A1). It is mounted to the hinged top cover of the AC-DC Power Processor. Connector J1 contains the three phase input power. Connector J2 contains the DC input signals and thyristor pulse drive signals.

The printed circuit assembly contains the three phase control power transformer, +12V voltage regulator, +5V voltage regulator, the undervoltage/overvoltage sensor electronics and the regulator control electronics, shown in the schematic (Figure 11).

Figures 17 and 18 show the left side power stage (subassembly) A2 and the right side power stage (subassembly A3), respectively.

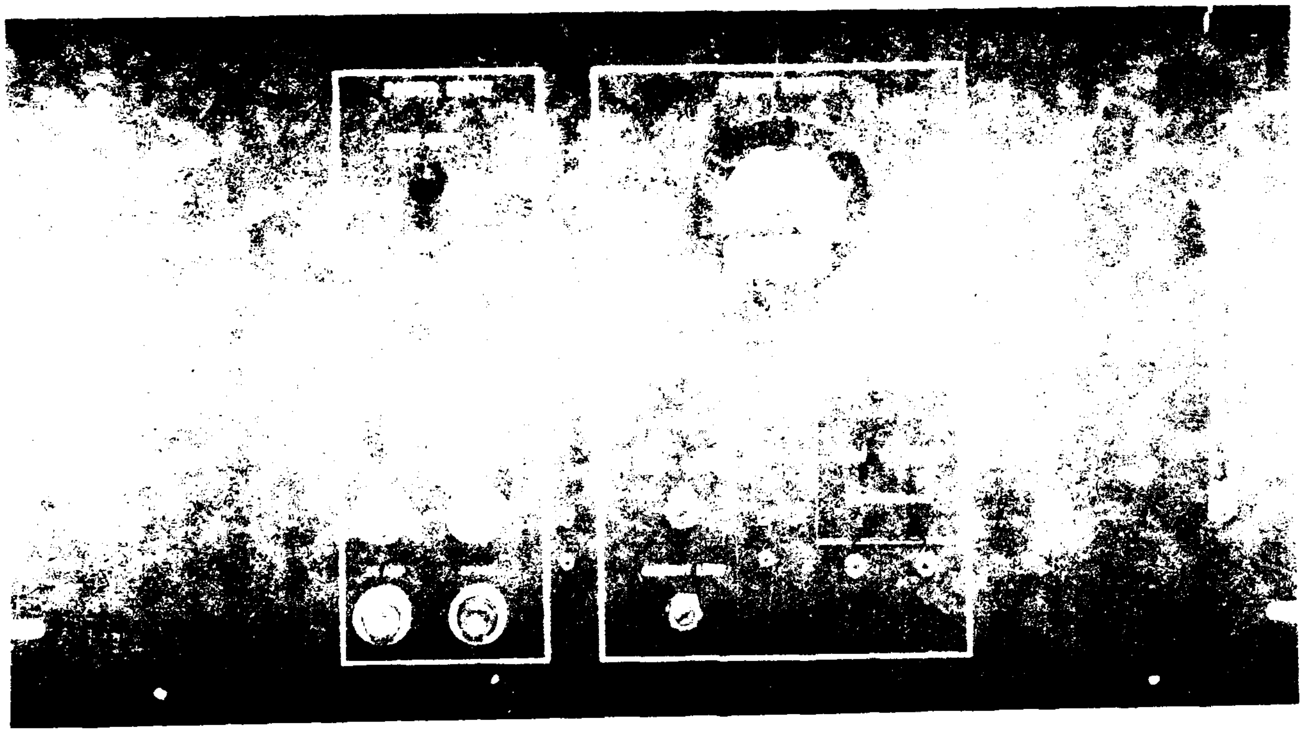


FIGURE 14 FRONT PANEL -- FRONT VIEW

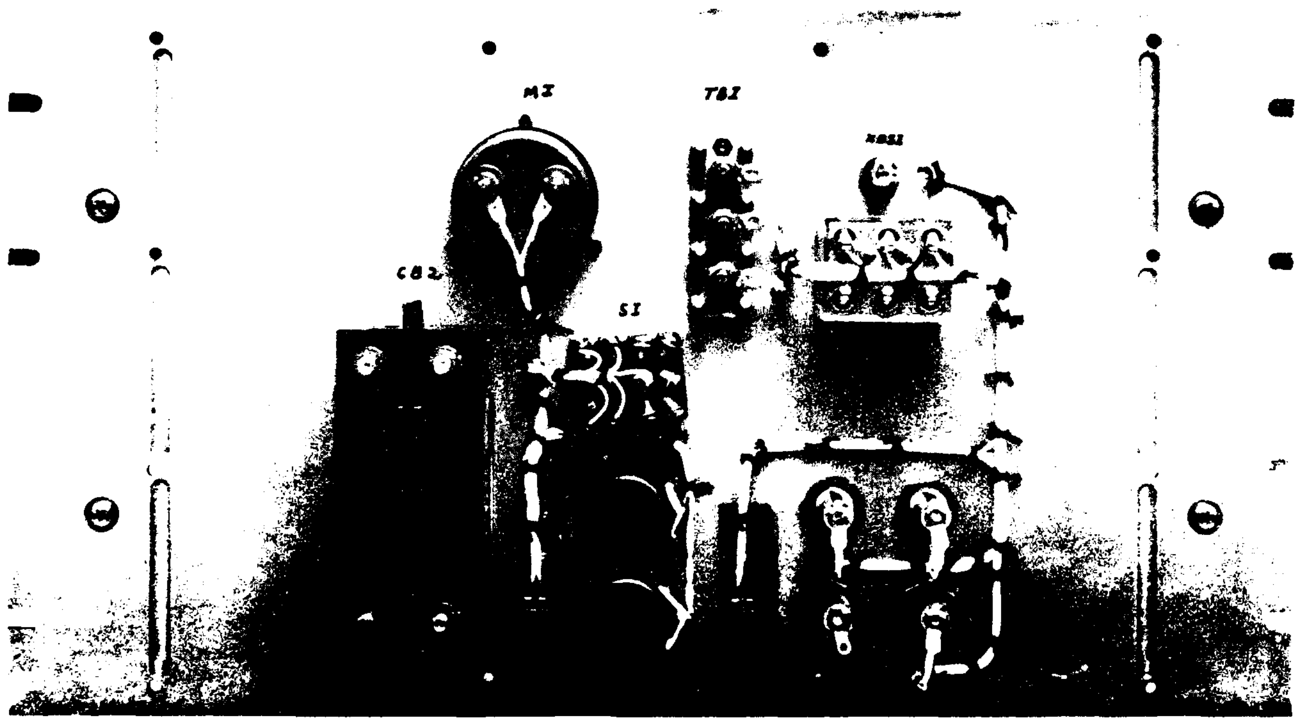


FIGURE 15 FRONT PANEL -- REAR VIEW

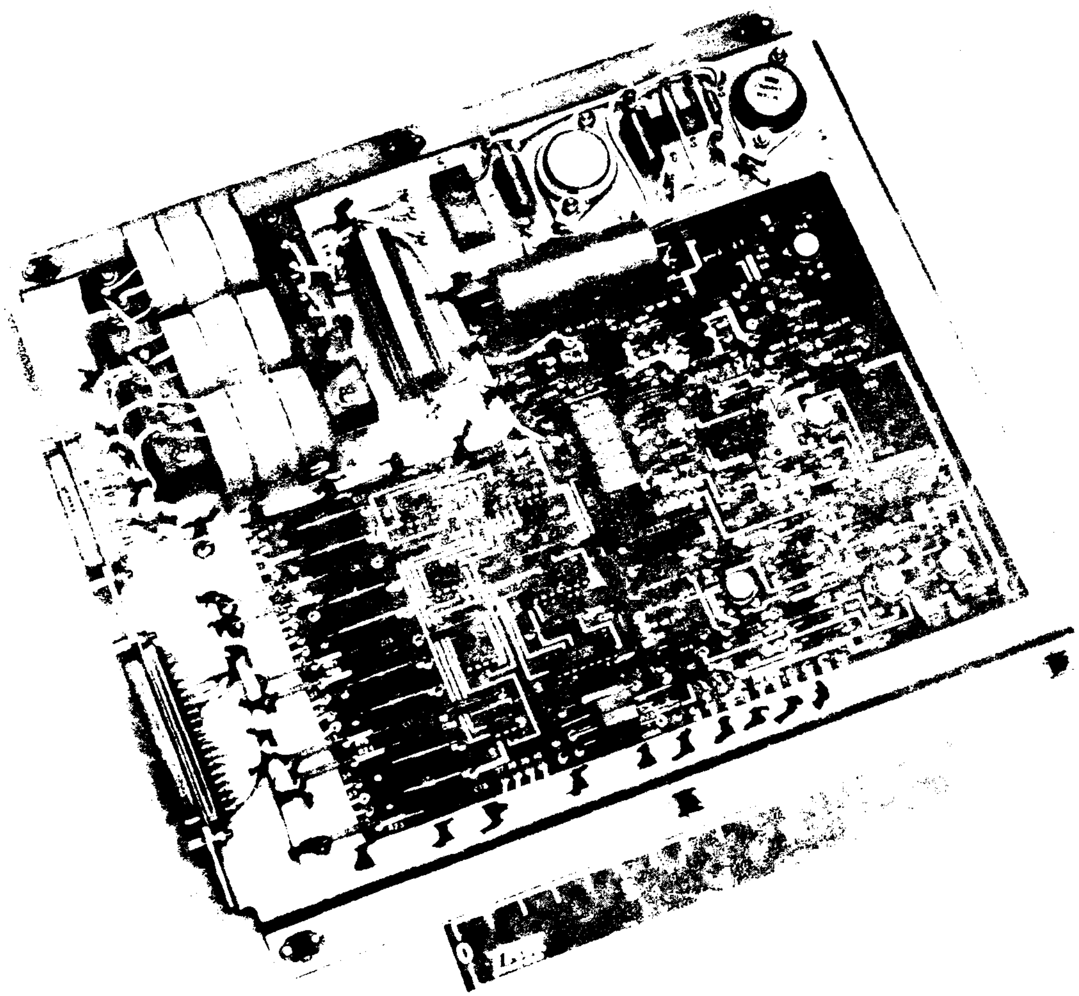


FIGURE 16 A1 PRINTED CIRCUIT BOARD

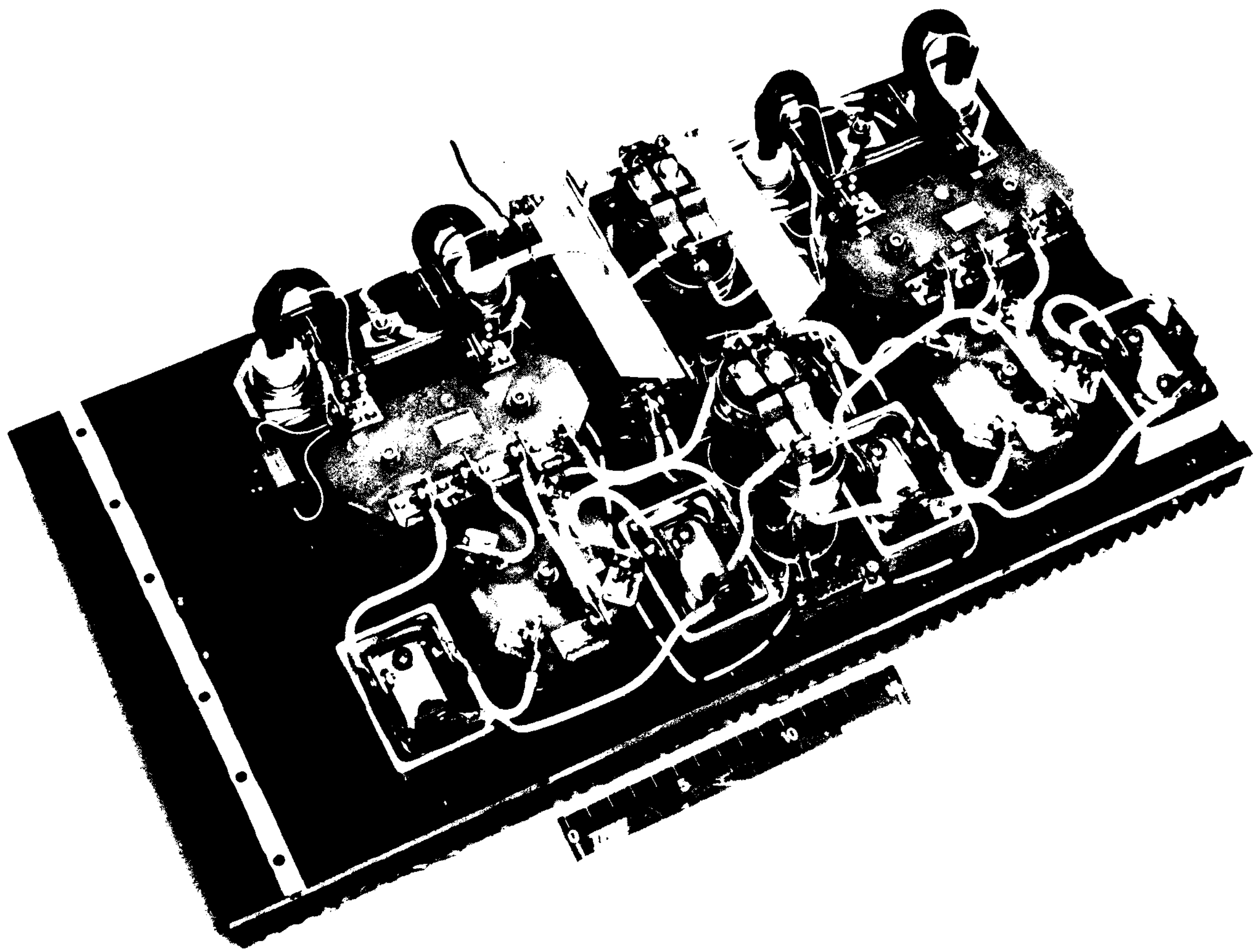


FIGURE 17   A2 POWER STAGE MODULE

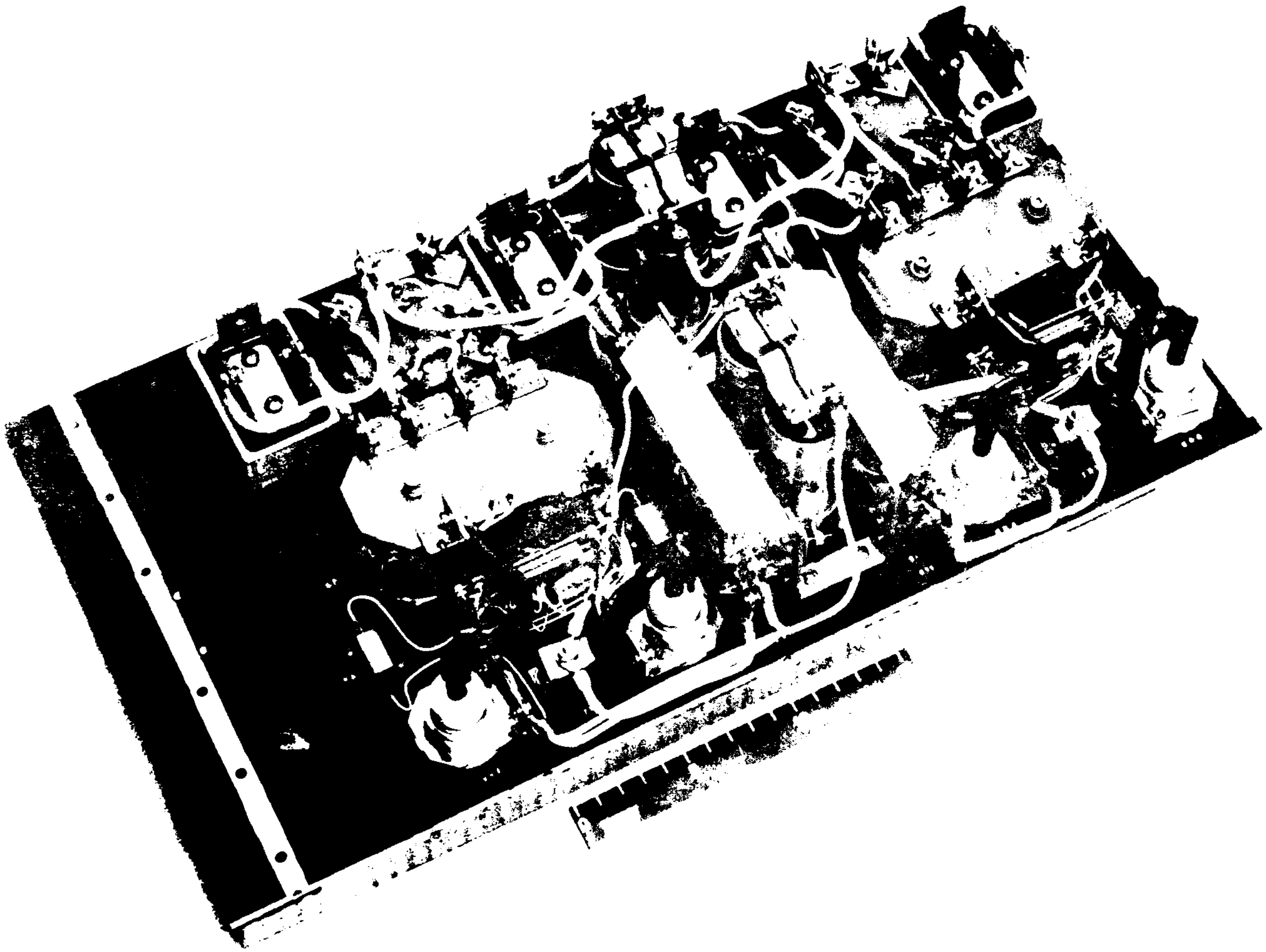


FIGURE 18   A3 POWER STAGE MODULE

In Figure 18 the power thyristors are located along the bottom edge which runs cooler than the top edge. In the bottom center is located the input filter capacitors and series resonant capacitors. The top center contains the output filter capacitors. The output power transformer and output rectifier diodes are mounted along the top edge. The dual reactor assembly between the thyristors and power transformer is comprised of the two series resonant inductors. The only special electrical insulating hardware is located under the power thyristors, thereby reducing the thermal resistance of all components mounted on the two side panels.

Figures 19 and 20 shows different views of the rear panel assembly (A4). In Figure 19 the input connector and high frequency EMI filter can be seen in the lower left corner. The low frequency EMI filter inductors and capacitors are mounted on the rear wall and top shelf of the extensions. The three-phase power bridge diode is also mounted on the rear panel. The output DC current shunt is mounted on the top right-hand corner. The output filter capacitors are mounted on the bottom shelf of the extension.

Figure 20 shows the output connector and EMI filter assembly in the bottom right corner. The output filter inductor is mounted above it.

Special safety notices have been placed on the top cover assembly, (1) for the weight limitation and the requirement for two men to carry the unit and (2) for internal high voltage which can injure the test personnel.

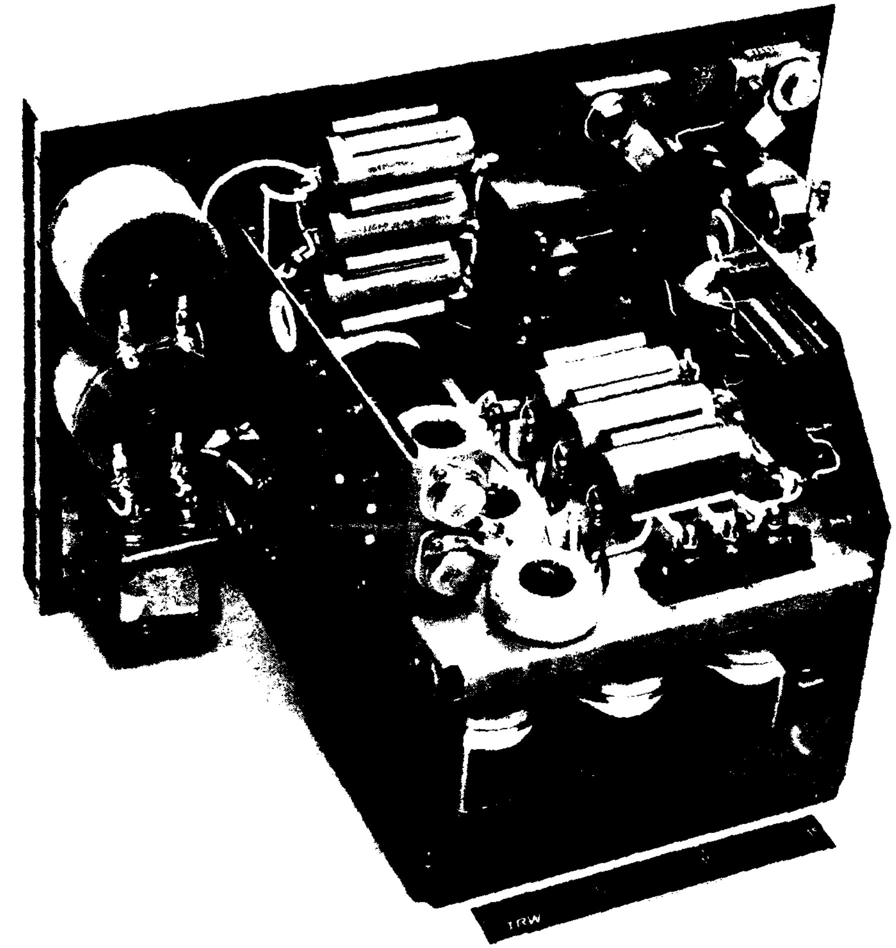


FIGURE 19   A4-REAR PANEL (LEFT SIDE VIEW)

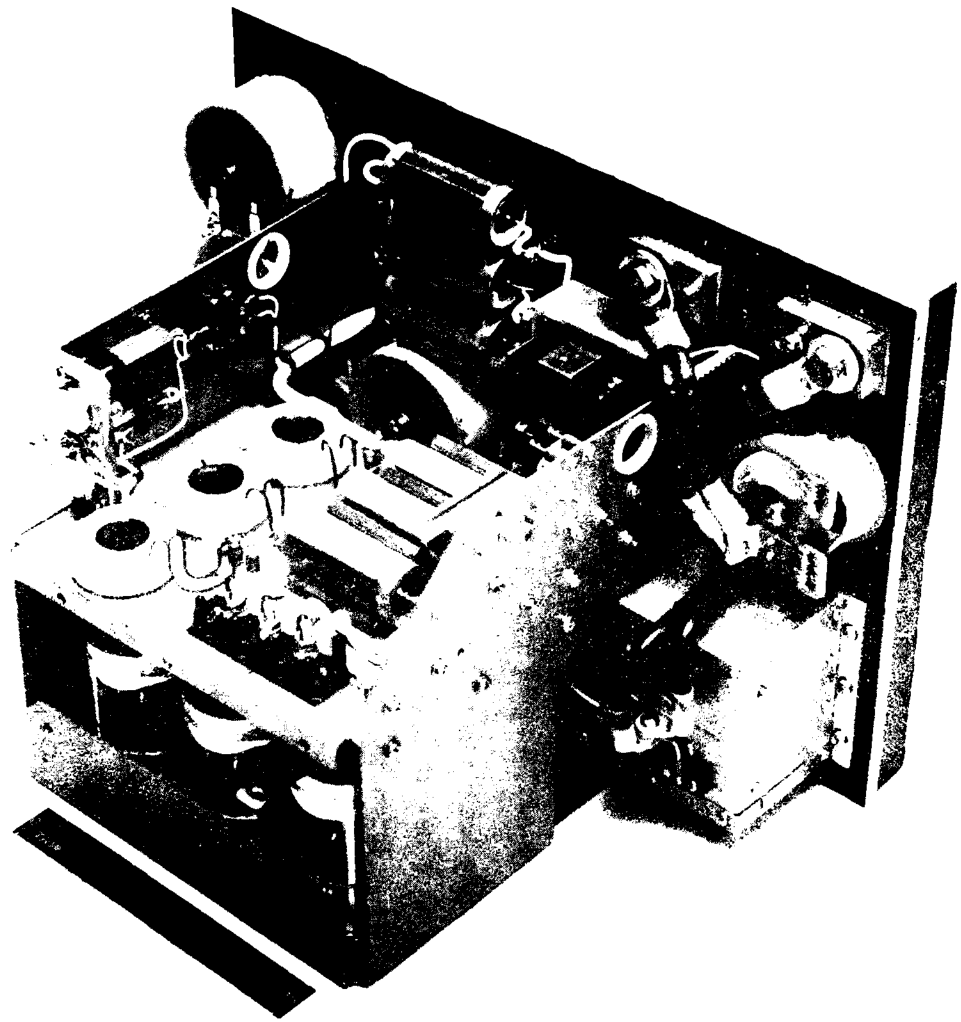


FIGURE 20 A4-REAR PANEL (RIGHT SIDE VIEW)

c. Thermal Design.

The advanced development model AC-DC Power Processor is designed to operate in a free convection environment without the use of external forced-air cooling.

A thermal mockup was fabricated to evaluate cooling technique and to devise a method to control the front panel temperature at 110°F. Based on the results of the thermal mockup tests, a thermal control technique was established.

All heat-producing components are mounted on the two-side finned heat sinks (Modules A2 and A3), Figures 17 and 18, and on the rear finned heat sink (Module A4), Figure 19.

On the side heat sinks (A2 and A3), the thyristors are mounted on the bottom edge in order to have the lowest operating temperature. Power magnetics are mounted in the center and the output rectifiers are mounted near the top edge since they can operate at higher temperatures.

The rear finned heat sink panel A4 has the three-phase bridge rectifiers, input EMI filter inductors, dc filter inductor, and output current shunt mounted on the surface.

The front panel does not have any heat producing components mounted on it. The thermal resistance between the front panel and side finned heat sinks is maximized so that the front panel will meet the 110°F maximum temperature limit when the unit is operated at 77°F ambient.

Every attempt is made to reduce component operating temperatures and to minimize the heat load injected into the internal trapped air. This trapped air causes the front panel temperature to rise.

d. Reliability Prediction.

A reliability prediction of the AC-DC Power Processor was performed in accordance with the procedure outlined in Section 3 of MIL-HDBK-217B.

The general expression for estimating the AC-DC Power Processor equipment failure rate based on Section 3, MIL-HDBK-217B methods is:

$$\lambda_{EQUIP} = \sum_{i=1}^{i=n} N_i \, (\lambda_G \pi_Q)_i$$

λ_{EQUIP} = total processor failure rate (failures/10^6 hr)

λ_G = generic failure rate for the i th generic part (failures/10^6 hr)

π_Q = quality factor for the i th generic part

N_i = quantity of i th generic part

n = number of different generic part categories

The estimated failure rate for each processor electrical part is tabulated in Table II.

Microelectric devices have an additional multiplying factor, π_L (learning factor) as defined in Table 3-4 of MIL-HDBK-217B. For items 44-50 of Table II, π_L was assumed to be 10 and is included in λ_G for each generic part.

The mean time between failure (MTBF) of the AC-DC Power Processor is estimated to be 11,580 hours. This value is greater than the contract requirement of 2,000 hr (MTBF) and therefore the basic electrical design does not present any problem in meeting the contract reliability requirement.

Of the total equipment failure rate of 86 x 10^{-6} failures per hour, 35 percent was due to the adjustable resistors, 35 percent was due to the power semiconductors and 20 percent was due to integrated circuits.

TABLE II. AC-DC POWER PROCESSOR - PARTS COUNT RELIABILITY PREDICTION

ITEM NO.	CKT REF	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER/P.N.		QTY (N)	GENERIC FAILURE RATE ($\lambda_G x10^{-6}$)	QUALITY FACTOR (πQ)	PREDICTED FAILURE RATE ($\lambda p x10^{-6}$)
1	A4CR1	3Ø BRIDGE - 33A/600V	SEM-TECH	SC3AS6A	1	.9	1	.9
2	A2 & 43 CR1-CR4	DUAL POWER RECT. 200PIV-FAST 100AMP	SEM-TECH	SCPASZA	8	.9	1	7.2
3	A1CR2-CR4	DIVIDE 100MA, 600V		1N5618	3	.9	1	2.7
4	A1CR1	3Ø BRIDGE 1AMP-100PIV	SEM-TECH	S3BR1	1	.9	1	.9
5	A1CR23, CR24	1AMP BRIDGE RECTIFIER 100PIV	SEM-TECH	SBR1F	2	.9	1	1.8
6	A1CR10-CR22	SIGNAL DIODE		1N3600	13	.68	1	8.84
7	A4VR1.2	POWER ZENER-200V/50W	MIL-S-19500/114 MOTOROLA	1N2846	2	.85	1	1.7
8	A1VR3-VR7	REFERENCE ZENER - 6.4V 1mA - .001% 1°C	MOTOROLA	1N4573A	5	.85	1	4.25
9	A2 & A3 VR1-VR4	SCR-60A-800V	WESTINGHOUSE	T507-084084	8	.9	1	7.2
10	A4L2-L4	EMI FILTER INDUCTOR	FAB.	D295087	3	.034	1	.102
11	A4L5-L7	EMI FILTER INDUCTOR	FAB.	D295088	3	.034	1	.102
12	A4L8	INPUT FILTER INDUCTOR	FAB.	D295089	2	.034	1	.068
13	A4L1	EMI FILTER INDUCTOR	FAB.	D295086	1	.034	1	.034
14	A4L9	OUTPUT FILTER INDUCTOR	FAB.	D295090	1	.034	1	.034

TABLE II. AC-DC POWER PROCESSOR - PARTS COUNT RELIABILITY PREDICTION

ITEM NO.	CKT REF	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER/P.N.		QTY (N)	GENERIC FAILURE RATE ($\lambda_G x10^{-6}$)	QUALITY FACTOR (πQ)	PREDICTED FAILURE RATE ($\lambda p x10^{-6}$)
15	A2 & A3 L1 & L2	SERIES INVERTER INDUCTORS 110μh - 37ADC PEAK	FAB.	D295094	8	.034	1	.272
16	A2 & A3 T3 & T6	POWER TRANSFORMER	FAB.	D295095	4	.034	1	.136
17	A1T1	3Ø TRANSFORMER - 10W 60Hz	FAB.	D295093	1	.034	1	.034
18	A2 & A3 T1,T2,T4,T5	SCR - PULSE DRIVER TRANSFORMERS	FAB.	D295096	8	.0045	1	.036
19	A4 T1 A2 T3 A2 L1	CURRENT TRANSFORMERS	FAB.	D295097	3	.0045	1	.0135
20	A4C1-C6	4μf-400V POLYCARBONATE INPUT EMI FILTER	COMP. RESEARCH	AB12E405KSC	6	.0012	1	.0072
21	A4C13-C14	2μf-50V POLYCARBONATE EMI FILTER	COMP. RESEARCH	M83421	2	.0012	1	.0024
22	A2 & A3 C1, C7	ELECTRO-LYTIC CAP. INPUT FILTER - 150μf - 450VDC	GE	86F241ALA	4	.11	1	.44
23	A2 & A3 C2,C3,C8,C9	.002μFd 1000V CAPACITOR	CUSTOM	CMR1A102202K	8	.06	1	.48
24	A2 & A3 C4,C5,C10,C11	POLYCARBONATE, 1000/ - 0.72μFd	COMP. RESEARCH	CR2004G724XL	8	.0012	1	.0096
25	A2 & A3 C6, C12	ELECT-LYTIC 2100μf - 40VDC	GE	92F227ALA	4	.11	1	.44
26	A4C7 to C12	ELECT-LYTIC 5500μf - 40VDC	GE	92F233ALA	6	.11	1	.66

TABLE II. AC-DC POWER PROCESSOR - PARTS COUNT RELIABILITY PREDICTION

ITEM NO.	CKT REF	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER/P.N.		QTY (N)	GENERIC FAILURE RATE ($\lambda_G x10^{-6}$)	QUALITY FACTOR (πQ)	PREDICTED FAILURE RATE ($\lambda p x10^{-6}$)
27	A4C15-C18	80μFd-50V POLYCARBONATE EMI FILTER	COMP. RESEARCH	AE12B806KSC	4	.0012	1	.0048
28	A2 & A3 C13,C14, C15,C16	0.01μFd ± 10% 200V	MIL-C-39014	M39014/02-1258	8	.0012	1	.0096
29	A1C9 to C16	0.47μFd 100V CERAMIC	MIL-C-39014		8	.0012	1	.0096
30	A1C4	TANTALUM SOLID 1μf, 50VDC	MIL-C-39003	M39003/01-2836	1	.052	1	.052
31	A1C1, C2	TANTALUM SOLID,10μf, 50VDC	MIL-C-39003	M39003/01-2854	2	.052	1	.104
32	A1C3,C5 C17	.01f/100V CERAMIC CAPACITOR	MIL-C-39014	M39014/02-1230	2	.044	1	.088
33	A1C26	.01f GLASS DIELECTRIC 500V (ULTRA STABLE)	MIL-C-11272	CY10C510F	1	.021	1	.021
34	A1 MISC	.1μFd, 50V, CERAMIC			18	.0012	1	0.0216
35	A1C35	10μf/15VDC TANTALUM		C253698-2099M	1	.11	1	.11
36	A4,R1,R6, R7	20W, 25Ω, WW NON INDUCTIVE	DALE MIL-R-18546	NCH-20-25	3	.18	1	.54
37	A2 & A3 R1,R2,R5,R6	200Ω 70W	MIL-R-18546	RE65G2000	8	.18	.1	1.44
38	R1, R2	2.5K POT WIRE, 2W FRONT PANEL	MIL-R-19A	RA20LASB252A	2	8.5	1	17.

TABLE II. AC-DC POWER PROCESSOR - PARTS COUNT RELIABILITY PREDICTION

ITEM NO.	CKT REF	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER/P.N.		QTY (N)	GENERIC FAILURE RATE ($\lambda_G x10^{-6}$)	QUALITY FACTOR (πQ)	PREDICTED FAILURE RATE ($\lambda p x10^{-6}$)
39	MISC	CARBON COMP.	MIL-R-39008		9	.0085	1	.0765
40	A1 MISC	FILM	MIL-R-55182/3		26	.042	.1	1.092
41	A1 MISC	TRIM POT	BOURNS	C259559-002	6	.9	1	5.4
42	A1R17 to R24	121 , WW	MIL-R-39007	RWR80S1210FR	8	.11	.1	.088
43	A4R8	0.5 W.W.	MIL-R-39007	RWR80SR500FR	1	.11	.1	.011
44	A1U7,U8	HEX INVERTER	T.I.	SN54L04	2	.91	1	1.82
45	A1U1,U10	QUAD COMPARATOR	NATIONAL	LM139	2	1.2	1	2.4
46	A1U3,U4,U5, U6	DUAL DRIVER	T.I.	25N55452	4	1.2	1	4.8
47	A1U9	RING COUNTER	RCA	CD4018AE	1	1.6	1	1.6
48	A1VR1	12V SERIES REG.	FAIRCHILD	UA7812KM	1	1.2	1	1.2
49	A1VR2	5V SERIES REG.	NATIONAL	M38510	1	1.2	1	1.2
50	A1AR1 to AR4	OPERATIONAL AMP	HARRIS	HA2520	4	1.2	1	4.8
51	A4J1	4 #12 30 INPUT		MS3102R20-4P	1	1	1	1
52	A4J2	2 #4 100A OUTPUT		MS3102R24-12S	1	1	1	1
53	CB1	3Ø 15A, BREAKER	HINEMAN	HB3Z1-69	1	.5	1	.5
54	CB2	DUAL CONTACT 100A BREAKER - CURVE #3	HINEMAN	2AM151-6HK-100-50VDC-3	1	.5	1	.5

TABLE II. AC-DC POWER PROCESSOR - PARTS COUNT RELIABILITY PREDICTION

ITEM NO.	CKT REF	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER/P.N.		QTY (N)	GENERIC FAILURE RATE (λ_Gx10^{-6})	QUALITY FACTOR (πQ)	PREDICTED FAILURE RATE (λpx10^{-6})
55	SW1	2P DT ON-NONE-MOMENTARY ON	CUTLER-HAMMER MIL-S-39500	8501K5	1	.1	1	.1
56	DS1	NEON LAMP 120VAC		NE51	1	.2	1	.2
57	M1	100MV FULL SCALE VOLT SCALE 0 TO %)V/i=0 TO 100A	WESTON	5226-8941	1	.5	1	.5
58	F1, 2, 3	FUSE HOLDER INDICATOR		FHL-17G-02	3	.1	1	.3
59		FUSE 1/4A, 3AG		313.250	3	—	—	—
60	R4	100MV SHUNT	WESTON	9992-041239	1	.0085	.01	.000085
61	A4J1A	DUST CAPS		MS9760-20	1	—	—	—
62	A4J2A	DUST CAPS		MS9760-24	1	—	—	—
							λ_{EQUIP}	= 86.35 X 10^{-6}
							$MTBF_{EQUIP}$	= 11,580 Hrs

e. Power Loss Analysis.

Table III shows a breakdown of the 453 watt power loss when the AC-DC Power Processor is operating at 28 volts 100 amps DC output. The calculated efficiency is 86.1 percent.

The power semiconductor losses account for 47 percent of the total power loss. The power magnetics dissipate 27 percent of the total losses. The remainder of the losses are in capacitors, shunt, cabling, and control electronics.

TABLE III. POWER LOSS ANALYSIS FOR AC-DC POWER PROCESSOR

(e_o = 28 VDC, I_o = 100 ADC)

ITEM		LOSS
Input EMI Filter		13 Watt
Input Rectifier		24 Watt
Input Filter Inductor		9 Watt
Input Filter Capacitors		12 Watt
	Per Power Stage	
SCR	22.5 Watt	90 Watt
RC Suppression	4 Watt	16 Watt
Inductors	10 Watt	40 Watt
Capacitors	2 Watt	8 Watt
Transformer	14 Watt	56 Watt
Rectifier	25 Watt	100 Watt
Output Filter Capacitor		12 Watt
Output Filter Inductor		5 Watt
Output Shunt		10 Watt
Output EMI Filter		10 Watt
Controls		12 Watt
Internal Cabling		36 Watt

TOTAL LOSSES 453 Watts

$$\text{EFFICIENCY} = \frac{2800}{2800 + 453} = 86.1\%$$

f. Weight Analysis.

Table IV shows the total weight of each subassembly and a breakdown of the mechanical hardware, electrical components and cabling weight. The mechanical hardware and electrical components account for 45% of the weight, respectively. The interconnecting cabling and wiring account for 10% of the total weight.

Table V lists all of the magnetic components used in the AC-DC Power Processor and account for 53% of the total electrical component weight.

Major reduction in weight can be obtained with the following changes:

1. Use of forced-air cooling.

2. Elimination of the three-phase input rectifier filter.

3. Use of higher internal switching frequencies.

Forced-air cooling would reduce the size of the finned heat sink and would allow smaller electrical power components to be used since component thermal resistance will not longer be a design driver. Perforated top and bottom covers would also eliminate internal tapped air.

Dr. F. C. Schwarz has a new circuit* that processes AC power to DC power without the use of the input low frequency bridge rectifier filter. This new circuit would reduce the input EMI filter and input low frequency filtering.

The new power transistor (D6T) from Westinghouse can be used in place of the slow switching thyristors and allow the operating frequency to increase from the present 10kHz to 20 or 30kHz without any penalty in efficiency but a reduction of the electrical component weight.

With these proposed changes, the packaged weight of 88.8 lbs. can be reduced to 60 lbs., or lower. The principal design constraint would be the heat removal of 450 watts.

*F.C. Schwarz, Patent No. 4,096,557, "Controllable Four Quadrant AC to DC Converter Employing an Internal High Frequency Series Resonant Link.

TABLE IV WEIGHT ANALYSIS FOR AC-DC POWER PROCESSOR

ITEM	TOTAL SUB-ASSEMBLY WEIGHT - LBS	WEIGHT BREAKDOWN		
		MECHANICAL HARDWARE WEIGHT-LBS	ELECTRICAL COMPONENT WEIGHT - LBS	CABLING & WIRING WEIGHT-LBS
Front Panel	6.5	3.4	2.8	0.3
A1 Control Card	2.4	0.6	1.6	0.2
A2 Left Side	22.7	10.4	11.2	1.1
A3 Right Side	22.7	10.4	11.2	1.1
A4 Rear Panel	25.3	10.2	13.9	1.2
Covers (Top & Bottom)	3.4	3.4	--	--
Frames (Top & Bottom)	1.4	1.4	--	--
Interconnecting Cabling Harness	4.4	--	--	4.4
TOTAL	88.8	39.8	40.7	8.3

TABLE V

MAGNETIC COMPONENT WEIGHT ANALYSIS

PART NUMBER	QUANTITY	NAME	WEIGHT gms ea.	TOTAL WEIGHT gms
D 29 50 86	1	Input EMI Common Mode Inductor	55	55
87	3	Input EMI AC Power Inductor	446	1338
88	3	Input EMI AC Shunt Inductor	126	378
89	1	DC Input Filter Inductor	1065	1065
90	1	DC Output Filter Inductor	276	276
91	1	Output Power EMI Inductor	106	106
92	1	Output Sense EMI Inductor	17	17
93	1	Control Transformer	535	535
94	4	Resonant Inductors (2L)	965	3860
95	4	Power Transformer	510	2040
96	8	SCR Drivers Transformer	5	40
97	3	Current Sense Transformer	10	30
TOTAL	MAGNETIC COMPONENT WEIGHT			9740 gms

21.5 lbs

4. SUMMARY OF TEST DATA.

The AC-DC Power Processor Advanced Development Model was fully tested. The following sections summarize the test results and is grouped into the following four subsections:

- Electrical Performance.
- Thermal Control.
- Electromagnetic Interference.
- Acoustic Noise.

a. Electrical Performance.

Complete electrical, temperature and continuous duty stability tests were performed with 60Hz and 400Hz 3 Ø AC input, and all data is contained in the Evaluation Report submitted to the U.S. Army Electronics Research & Development Command, Fort M nmouth, N.J. The following sections summarizes the results of this test data.

Table VI summarizes the output voltage regulation when the input line is varied from 108VAC to 132VAC (line to neutral). The unit is well within specification limits.

Table VII summarizes the output regulation with local sense when the output load is varied from 1.6A to 100ADC. The unit meets specifications but the voltage regulation is high due to the internal IR drop due to the circuit breaker, internal power cable, output EMI filter and output connector.

Table VIII summarizes the output regulation with remote sense on the end of the 25 ft. power cable. The output regulation is greatly improved over Table VII. No instability or oscillation was noted during the remote sense operation.

Table IX presents the output regulation due to ambient temperature change from -25°F to +145°F.

Table X presents the output long-term voltage stability as a function of time during the 72 hour continuous operation test. The unit is within the specification requirement.

TABLE VI OUTPUT REGULATION DUE TO LINE CHANGE

e_o	Δe_o (e_{in} 108 to 132VAC) I_o = 100ADC	Spec. ± 1%
24VDC	2mV	480mV
28VDC	10mV	560mV
32VDC	5mV	640mV

TABLE VII OUTPUT REGULATION DUE TO LOAD CHANGE (LOCAL SENSE)*

e_o	Δe_o (I_o = 1.6 to 100A)	Spec. ± 1%
24VDC	188mV	480mV
28VDC	184mV	560mV
32VDC	191mV	640mV

*At output connector terminals

TABLE VIII OUTPUT REGULATION DUE TO LOAD CHANGE (REMOTE SENSE)*

e_o	Δe_o (I_o = 1.6 to 100A)	Spec. ± 1%
24VDC	20mV	480mV
28VDC	20mV	480mV
29VDC	20mV	480mV

* At the end of 25ft cable.

TABLE IX AMBIENT TEMPERATURE OUTPUT REGULATION

TEMPERATURE	Δe_o (e_{in} = 120VAC) (e_o = 28VDC) (I_o = 100ADC)	SPEC $\pm$ 1%
145°F	-115mV	280mV
-25°F	+119mV	280mV

TABLE X OUTPUT VOLTAGE STABILITY

TIME	e_o (e_{in} = 120VAC) (I_o = 100A)	Δe_o
0 Hr.	28.016	0
4 Hr.	27.998	-18mV
15.5 Hr.	28.002	-14mV
17.5 Hr.	27.997	-19mV
21.0 Hr.	28.002	-16mV
24.5 Hr.	28.003	-13mV
39.5 Hr.	28.003	-13mV
44.5 Hr.	28.005	-11mV
48.5 Hr.	28.006	-10mV
63.5 Hr.	28.010	-6mV
68.5 Hr.	28.007	-9mV
72.0 Hr.	28.010	-6mV
SPEC		$\pm$ 0.5% $\pm$ 140mV

Table XI presents the output ripple as a function of output voltage and output current. Both the RMS value and peak-to-peak values are presented. The unit meets specification requirements.

Figure 21 shows the output current limit during overload testing and meets the 5% specification requirements.

Figure 22 shows the output voltage transient response and recovery time during turn-on into a light load and 100A load and load step transient between light to 100A load. During turn-on, there is an overshoot of about 1 volt (4%) and takes 6ms to recover (Figure 22). During step load transients, the maximum output deviation (Figure 22c) is about 0.5V (2%) and recovery time is 6ms maximum. The specification limits are 10% overshoot and 25ms recovery time.

Figure 23 shows the AC-DC Power Processor efficiency when supplied with a DC input where accurate digital voltage measurements can be made on input voltage and input current. The control electronics module was supplied with an external low voltage supply. The efficiency is a function of output voltage since the output rectifiers drop is a large percentage of the output voltate value.

Figure 24 shows the output impedance of the AC-DC Power Processor. This data is presented as reference information since there is no specification requirements.

The AC-DC Power Processor was also tested as a battery charger where it would charge at the current limit established by the front panel control. When the charge reached its voltage limit, the unit would operate at a constant voltage and the charge current was tapered back. No instability or oscillations were noted during this mode of operation.

TABLE XI OUTPUT RIPPLE

I_o	RIPPLE V_{in} (L-N) = 120VAC					
	e_o = 24VDC		e_o = 28VDC		e_o = 32VDC	
	V_{P-P}	V_{RMS}	V_{P-P}	V_{RMS}	V_{P-P}	V_{RMS}
1.0	300mV	40mV	200mV	32mV	190mV	28mV
20	200mV	19mV	200mV	17mV	190mV	20mV
40	220mV	28mV	220mV	29mV	220mV	30mV
60	230mV	34mV	240mV	37mV	250mV	42mV
80	240mV	40mV	260mV	46mV	260mV	42mV
100	270mV	47mV	260mV	45mV	270mV	50mV
SPEC	± 1% 480mV	0.5% 120mV	± 1% 560mV	0.5% 140mV	± 1% 640mV	0.5% 160mV

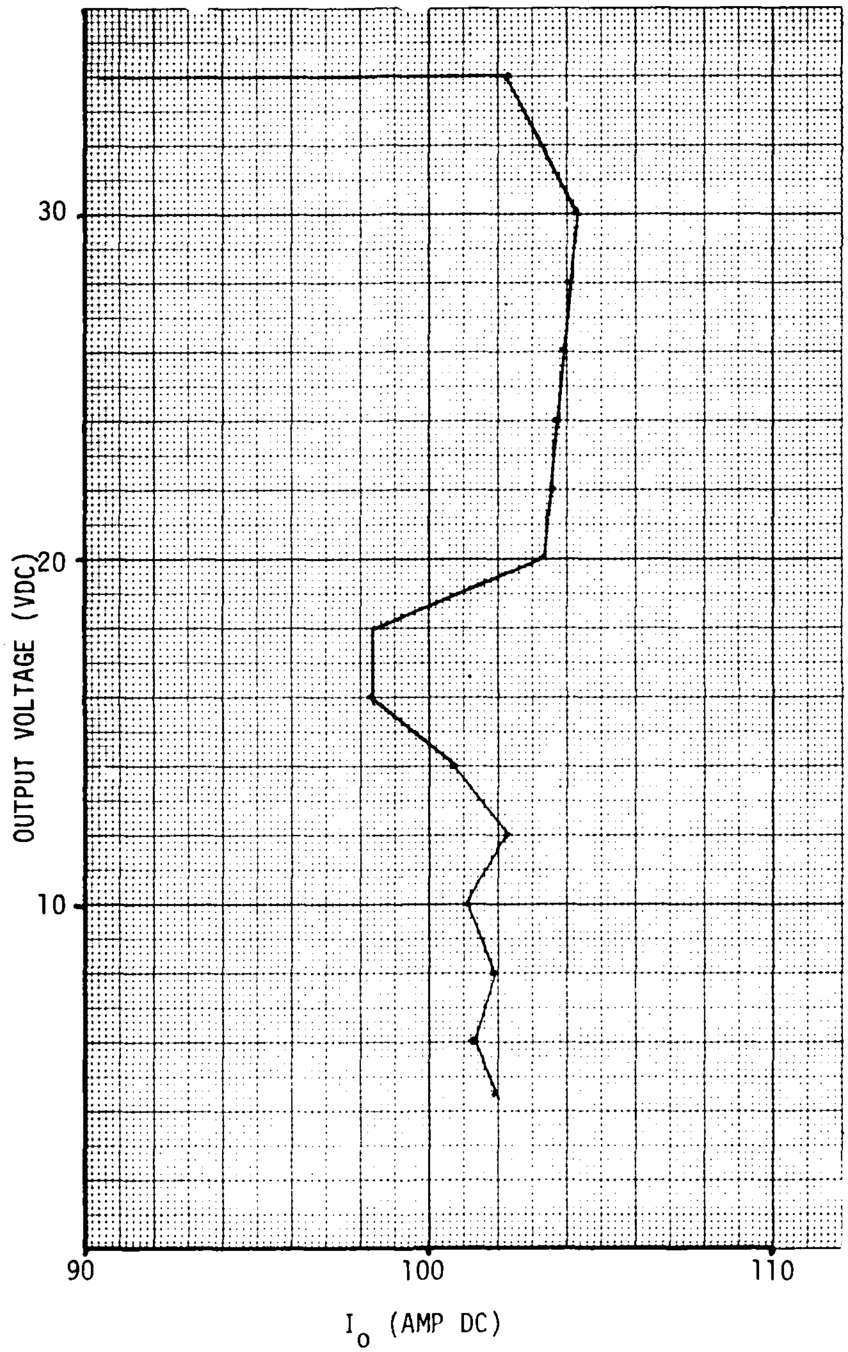
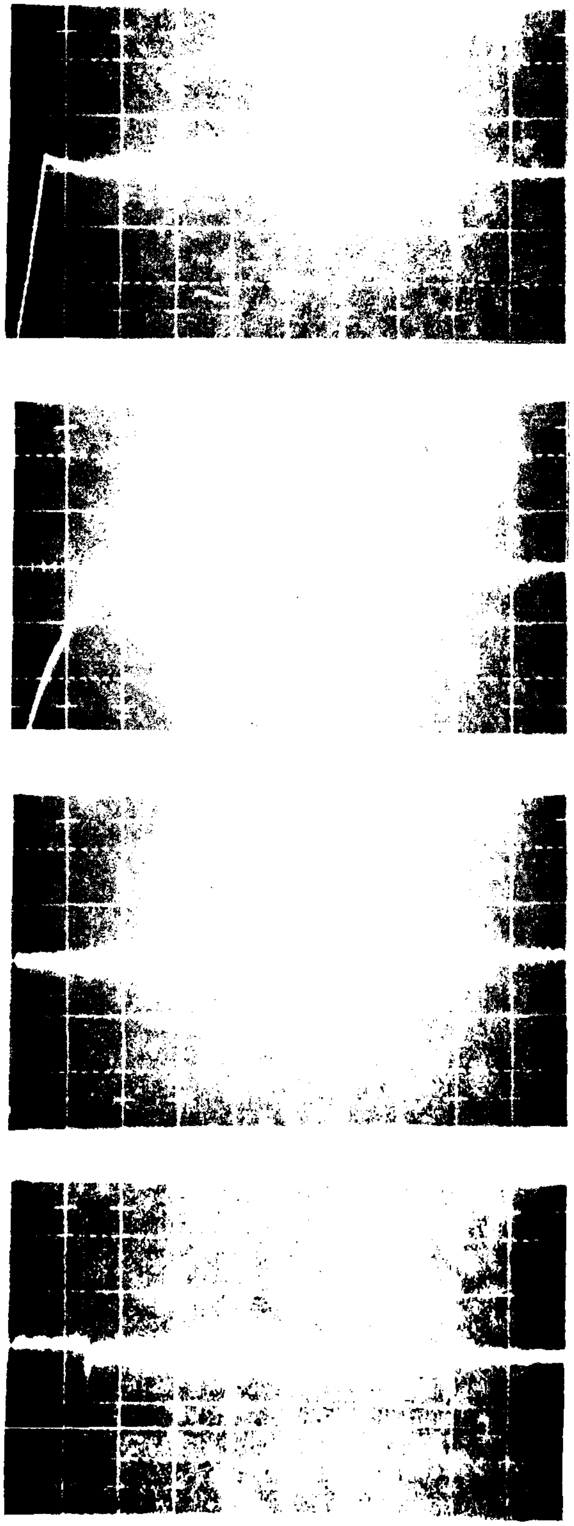


FIGURE 21 OVERLOAD CURRENT LIMIT

Eo = 28V
Ein = 132V; 60HZ



a) Turn-on Transient
Io = 1.4A
V = 5V/div
HORIZ = 20ms/div

b) Turn-on Transient
Io = 100A
V = 5V/div
HORIZ = 20ms/div

c) Load Transient
Io = 100A to 1.4A
V = 1V/div
HORIZ = 20ms/div

d) Load Transient
Io = 1.4A to 100A
V = 1V/div
HORIZ = 20ms/div

FIGURE [illegible] OUTPUT VOLTAGE TRANSIENT AND RECOVERY TIME

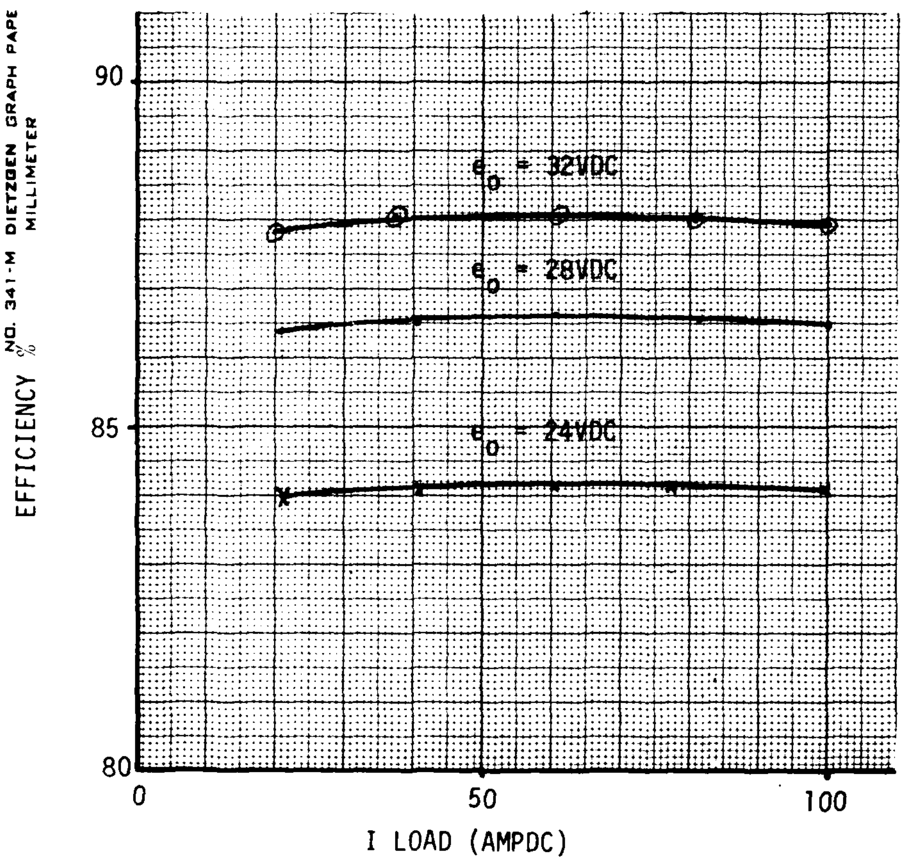


FIGURE 23 EFFICIENCY

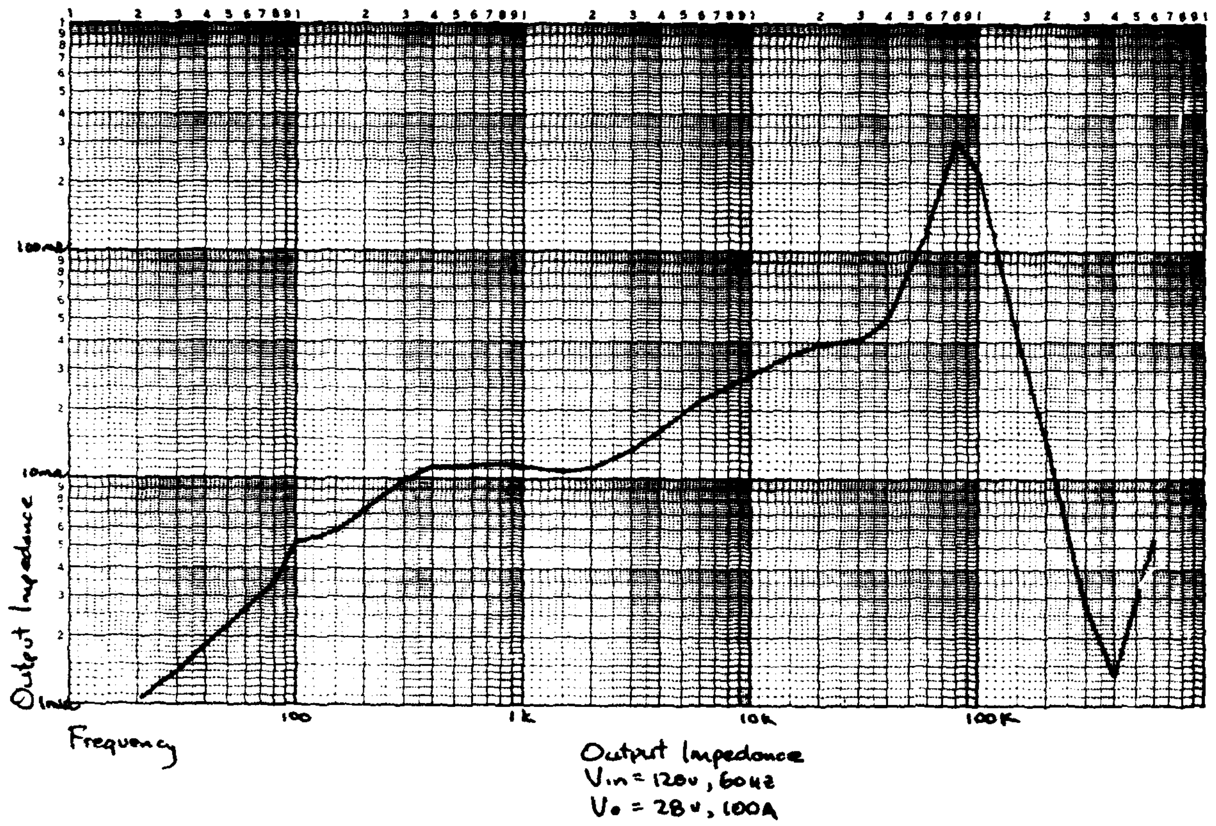


FIGURE 24 OUTPUT IMPEDANCE

b. Thermal Profile Tests.

All heat producing components were mounted on the two side-finned heat sinks and rear-finned heat sink. The front panel was thermal isolated to provide safety for the operating personnel.

Table XII shows the test results on the unit at the end of 72 hours test running at 28V, 100A output. The test results show a cool front panel (118°F) in a 83°F ambient temperature. The hottest exposed part temperature was 155°F. The hot spot internally was the output power transformer 203°F.

Table XIII shows the test results on the unit after stabilization at 145°F ambient temperature. The hot spot temperature was the output power transformer 210°F.

c. Electromagnetic Interference Tests

The following electromagentic interference tests were performed at 60Hz and 400Hz input frequency and output loading of 50 and 100ADC.

- Conducted Emission

CE01	DC power	30Hz to 50kHz
CE02	AC power	10kHz to 50kHz
CE04	Power leads	50kHz to 50MHz NB
CE04	Power leads	50kHz to 50MHz BB

- Radiated Emission

RE02	E-Field	NB
RE02	E-Field	BB

- Conducted Susceptibility

CS02	Power leads	50kHz to 400MHz
CS06	Power leads, Spike	

- Radiated Susceptibility

RS03	E-Field	15kHz to 400MHz

A separate EMC evaluation test report was submitted to the U.S. Army Electronics Research & Development Command that contains all of the detailed test data. A brief summary is contained in the following section. The electromagnetic interference specification for the AC-DC Power Processor is MIL-STD-461, Notice 4.

TABLE XII – AC-DC POWER PROCESSOR TEMPERATURE PROFILE AT 83°F AMBIENT (COMPONENT AND UNIT TEMPERATURES AT END OF 72 HOUR TEST)

T.C. NO.	LOCATION	TEMP °F
1	Outside Ambient	83
2	Outside-Front Panel	118
3	Outside-Left Side-Opposite Rectifiers	152
4	Outside-Left Side-Adjacent SCR's	152
5	Outside-Right Side-Opposite Rectifiers	155
6	Transformer-Left Side	203
7	PC Board Surface	157
8	Input Filter Capacitor	165
9	Output Filter Capacitor	175
10	Right Side Rectifier Case	175
11	Left Side SCR Case	161
12	Air Just Below PC Board	168

TABLE XIII – AC-DC POWER PROCESSOR TEMPERATURE PROFILE AT $T_{amb.}$ = 145°F. (COMPONENT AND UNIT TEMPERATURES AFTER STABILIZATION)

T.C. NO.	LOCATION	TEMP °F
1	Outside Ambient	145
2	Outside-Front Panel	151
3	Outside-Left Side - Opposite Rectifiers	166
4	Outside-Left Side - Adjacent SCR's	164
5	Outside-Right Side - Opposite Rectifiers	160
6	Transformer-Left Side	210
7	PC Board Surface	---
8	Input Filter Capacitor	—
9	Output Filter Capacitor	181
10	Right Side Rectifier Case	175
11	Left Side SCR Case	—
12	Air Just Below PC Board	177

c.1. Conducted Emission (CE01, CE02, CE04)

- DC Power Line CE01

Figure 25 shows the conducted narrowband emissions on the DC output power line with 60Hz input power. The maximum out of specification condition is about 12db μA. With 400Hz input power, additional narrowband frequencies appear in the output. The maximum out of specification condition increases to about 22db μA.

- AC Power Line CE02

Figure 26 shows the narrowband conducted emission with 60Hz input. The unit is withi specification limits.

Figure 27 shows the narrowband conducted emission with 400Hz input. A maximum out of tolerance condition is 18db μA. Part of the conducted emission is due to the 400Hz power generator, since power lines did not pass through an EMI filter to eliminate all harmonics from the power generator.

- AC & DC Power Lines CE04

The DC output power line did not have any narrowband conducted emissions and met specification limit.

Figure 28 shows the broadband conducted emissions on the DC output power line with 60Hz input power. It has a maximum out of tolerance condition of 20 dbμV/MHz. With 400Hz input power the out of tolerance condition reduces to 5dbμV/MHz.

The AC input power line did not have any narrowband conducted emission and met specification limit.

Figure 29 shows the broadband conducted emissions on the AC input power line with 60Hz input power. It has a maximum out of tolerance condition of 25dbμV/MHz at 1.5Hz. With 400Hz input power the out of tolerance condition reduces to 10dbμV/MHz.

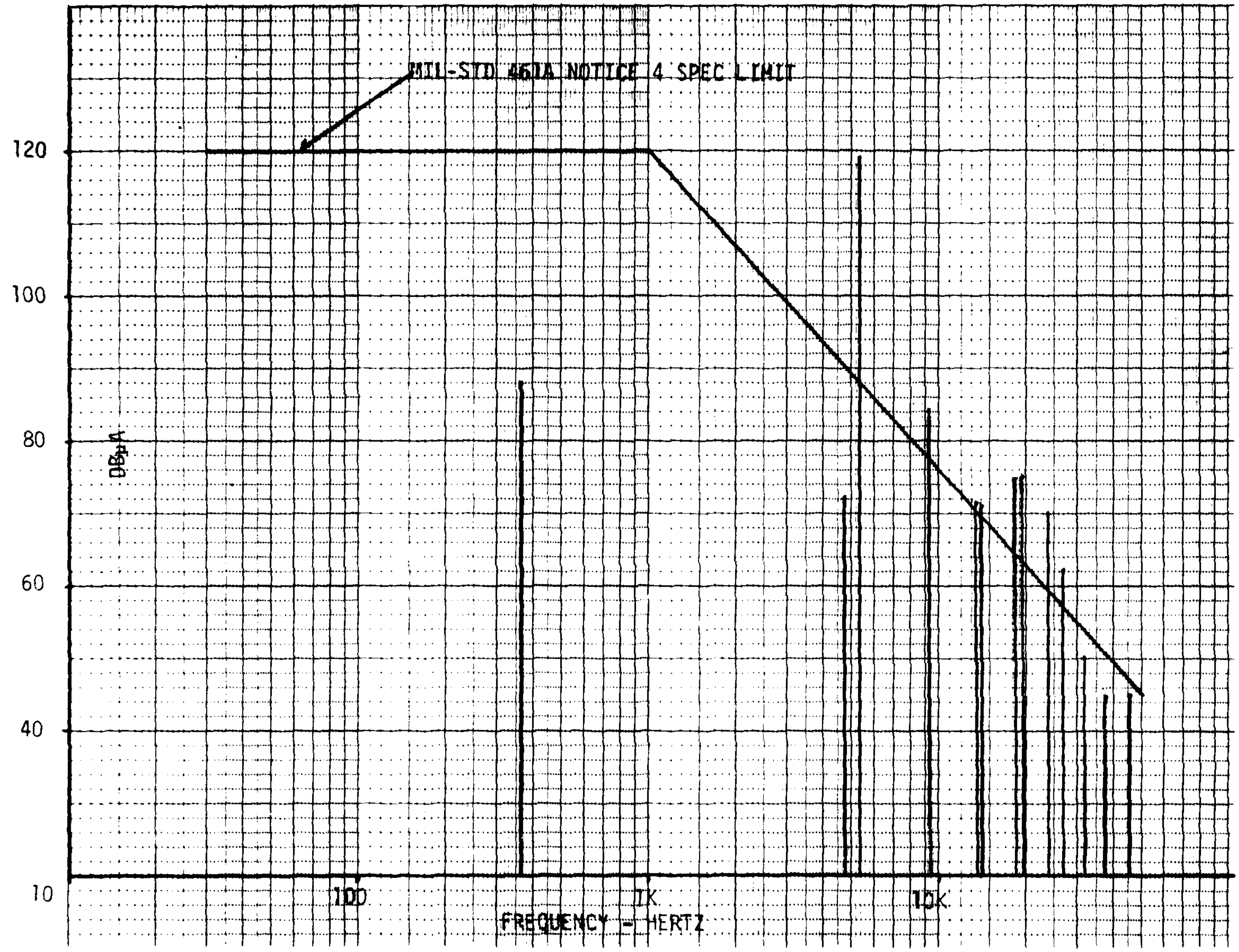


FIGURE 25 DC POWER LINE (CE01) CONDUCTED EMISSION

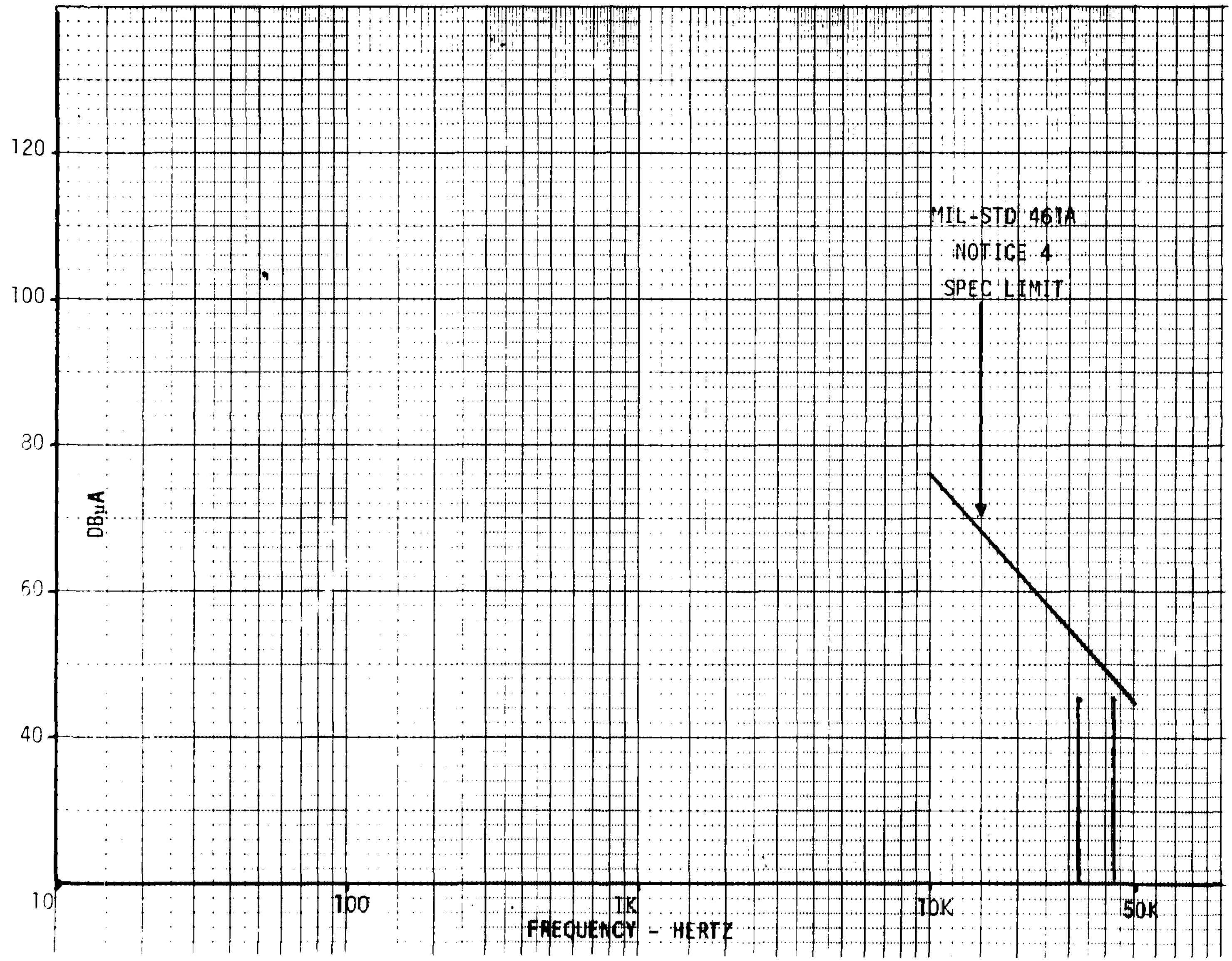


FIGURE 26 AC POWER LINE (CE02) CONDUCTED EMISSION AT 60 HERTZ

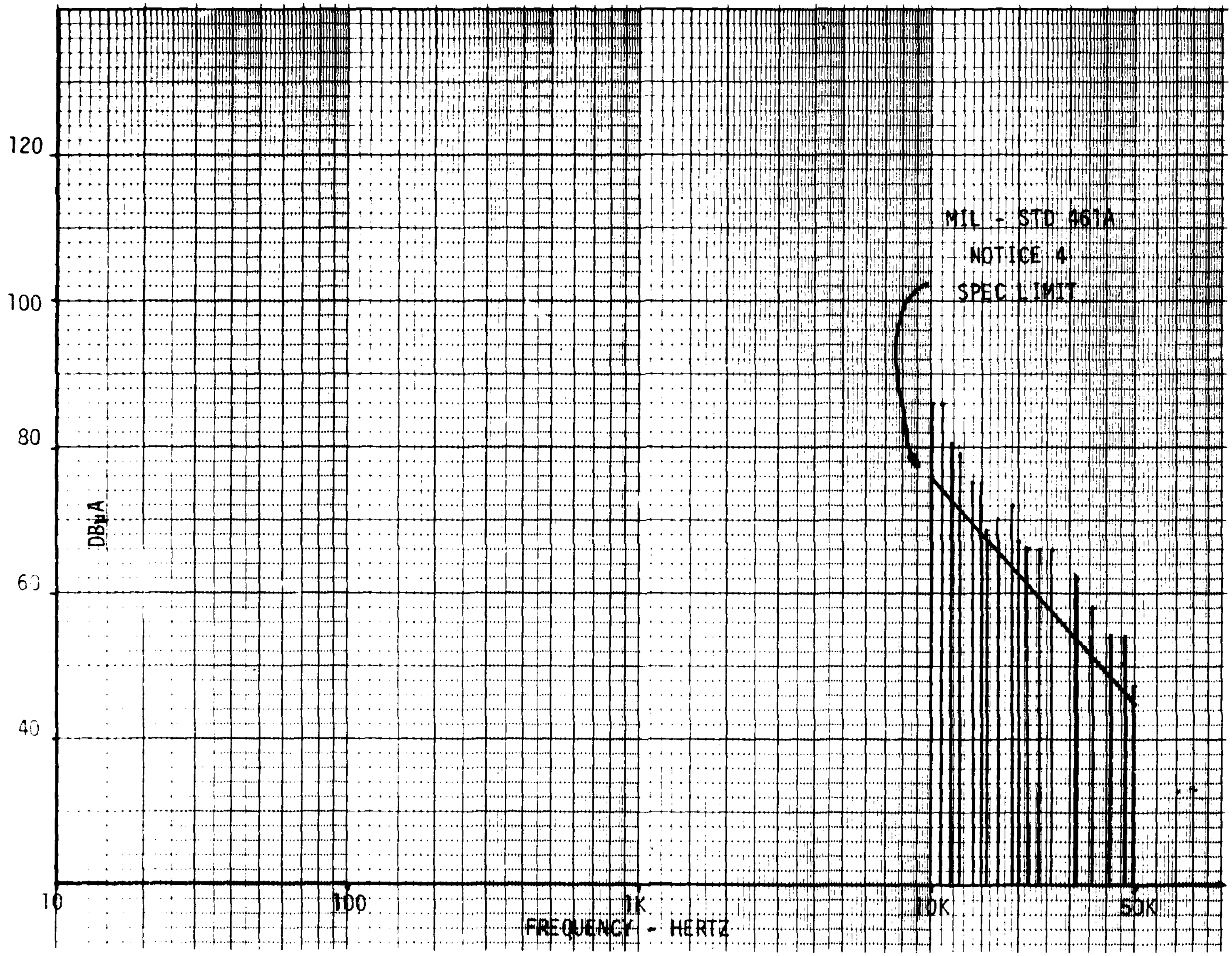


FIGURE 27 AC POWER LINE (CE02) CONDUCTED EMISSION AT 400 HERTZ

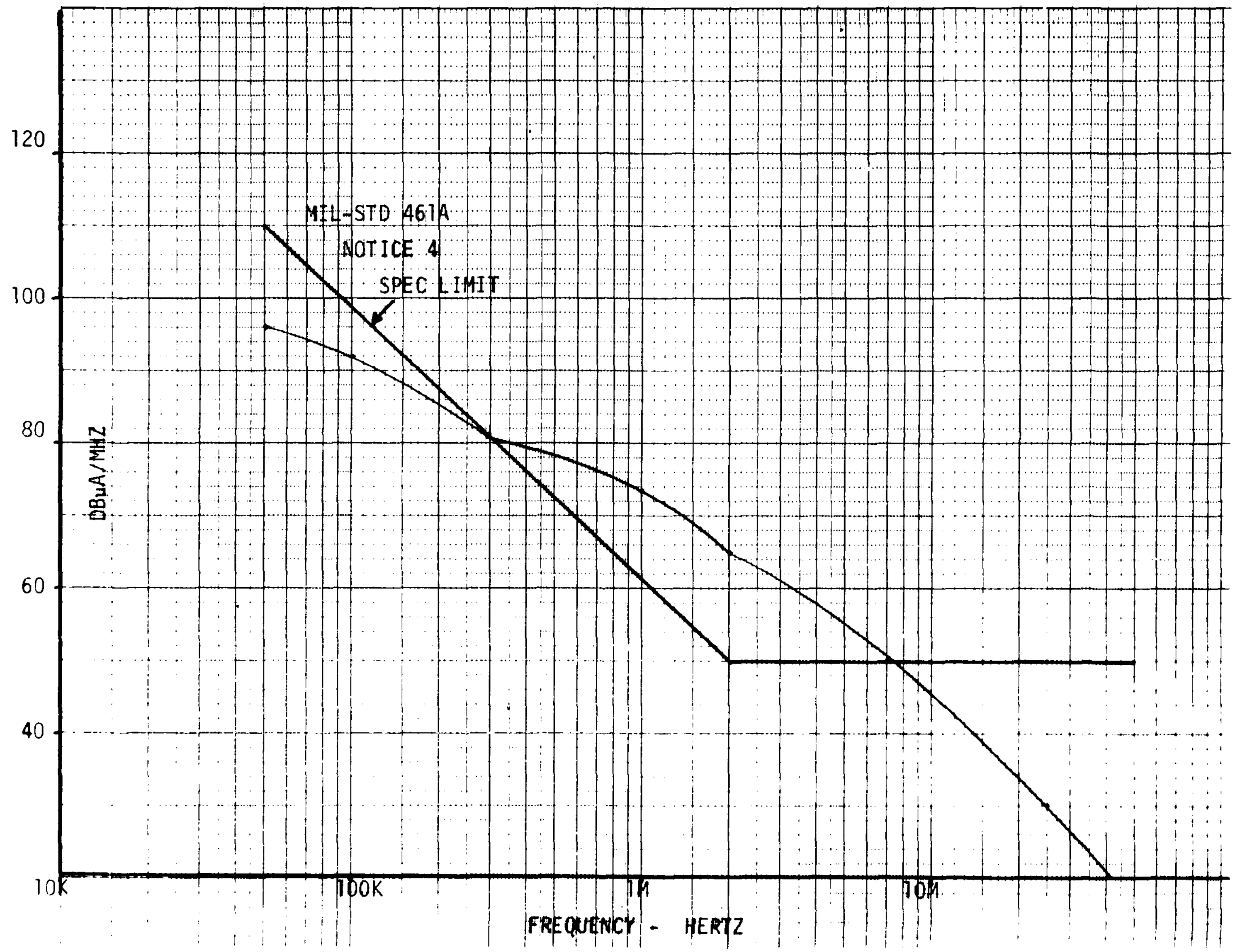


FIGURE 28 DC POWER LINE (CE04) CONDUCTED EMISSION

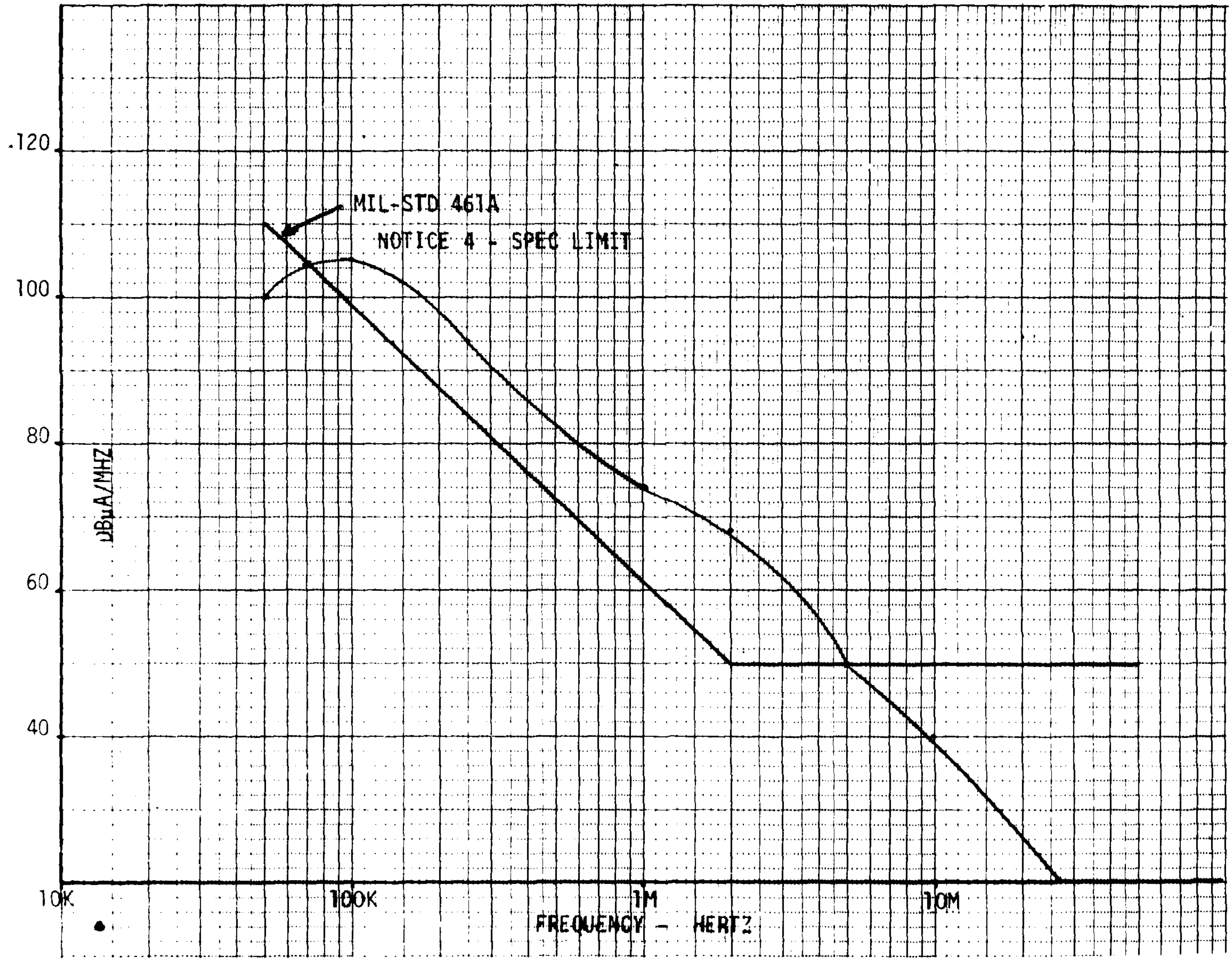


FIGURE 29 AC POWER LINE (CE04) CONDUCTED EMISSION

c.2 Radiated Emissions (RE02).

Figure 30 presents the narrowband radiated emissions in the 15kHz to 50kHz range. Maximum out-of-specification conditions were about 40db due to series resonant inverter switching frequency.

Figure 31 presents the broadband radiated emissions in the 15kHz to 2MHz range. Out-of-specification conditions are about 10db.

Additional EMI shielding and gaskets are required between mechanical subassemblies in order to reduce the radiated emissions.

c.3 Conducted Susceptibility (CS02, CS06).

No indication of susceptibility was roted as a result of the injection of required susceptibility signals onto the input power lines during the CS02 test.

During conducted susceptibility, spike test CS06, noise exceeding the + 0.28V peak-to-peak ripple voltage limit occurred when input spike peak was 75V min vs. a specification limit of 100V. This ripple was seen in the AC-DC power processor both when power was turned on and turned off. This indicated that a ground plane current was coupled between the input high frequency EMI filter and output EMI filter.

c.4 Radiated Susceptibility (RS03)

No indications of susceptibility were observed with the AC-DC Power Processor when irradiated at the required field levels.

d. Acoustic Noise Test.

Acoustic noise measurements were made on the Advanced Development Model using the General Radio type 1933 sound system analyzer in the "A" filter mode at 5 ft. distance from the unit. The worst case noise was radiated from the sides. Table XIV contains the test results of the ambient temperature at 100A and 50A output conditions The unit met the specification limit by at least 7db margin.

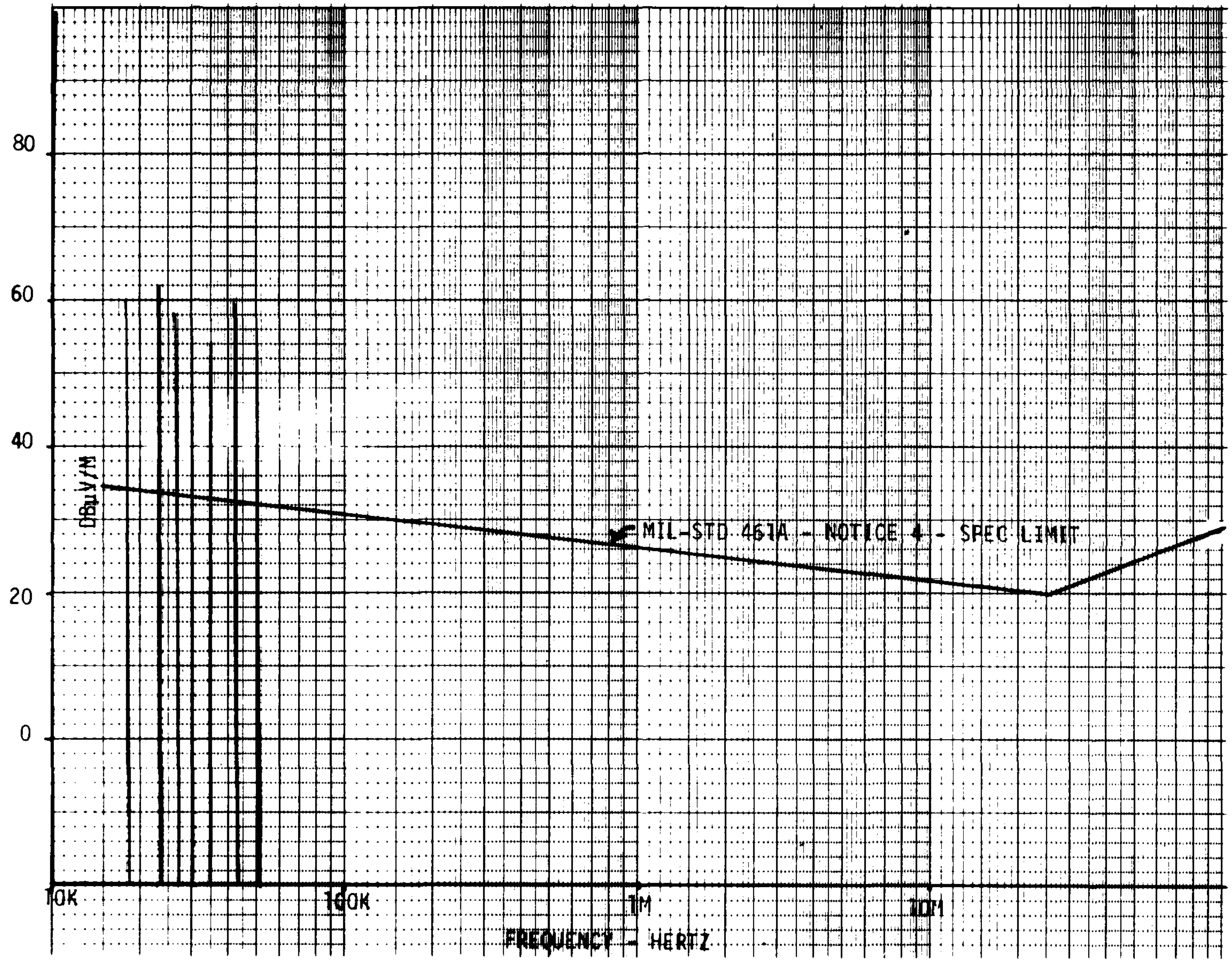


FIGURE 30 NARROWBAND RADIATED EMISSION (RE02)

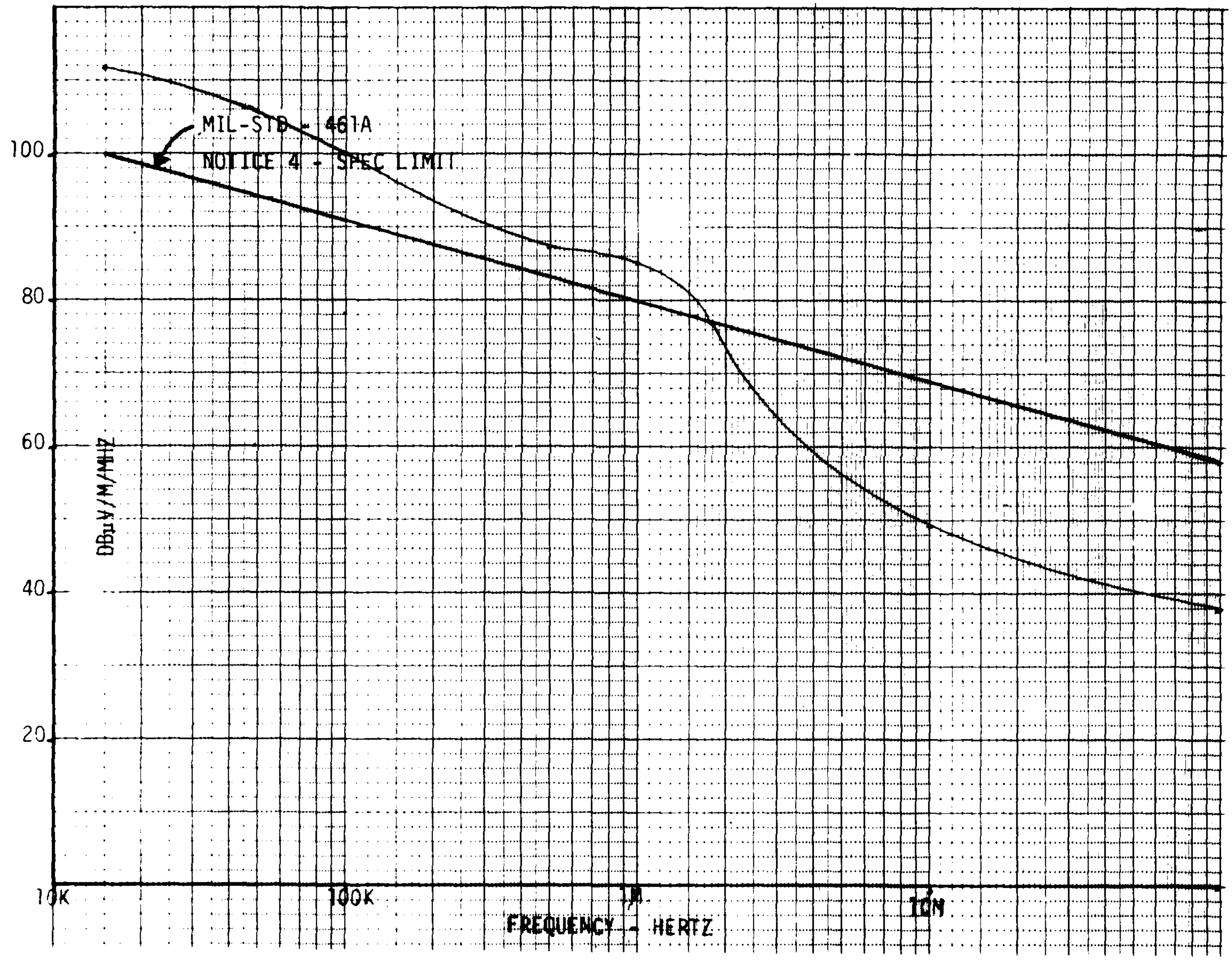


FIGURE 37 BROADBAND RADIATED EMISSION (RE02)

TABLE XIV ACOUSTIC NOISE TEST

OCTAVE BAND CENTER FREQ. (HZ)	LIMITS DB	MEASURED LEVEL		
		A) AMBIENT (Unit Off)	B) 28V, 100A (Output)	C) 28V, 50A (Output)
125	54	43	43	44
250	42	33	36	35
500	40	28	29	31
1000	35	19	20	20
2000	36	13	16	18
4000	41	14	28	22
8000	43	16	36	33

5. CONCLUSIONS

The advanced development model AC-DC Power Processor described in this report demonstrates a significant advance in power processing technology.

The following is a summary of the milestones accomplished:

1) Development of thyristor series resonant inverter power stage that control the energy in the inductive and capacitive resonant components and therefore controls the peak current and voltage stresses on the power components during all modes of operation.

2) Phase displaced operation of four separate power modules from one common output voltage regulator with excellent regulation and transient response and reduced input/output filtering requirements.

3) Mechanical packaging that facilitates maintainability.

4) Thermal control concept that ensures adequate component operating temperature.

The Advanced Development Model of the AC-DC Power Processor shows major improvements on the Demonstration Model developed in 1969 on Contract DAAB07-70-C-0245 in the following areas:

- Low acoustic noise
- Improved EMI characteristics
- Improved thermal characteristics.

6. RECOMMENDATIONS.

The requirements for free convection cooling and the use of standard electrical components greatly penalize the size and weight of the advanced development model AC-DC Power Processor.

All shelter installations have forced-air cooling provisions. This forced-air cooling would allow the reduction of the size and weight of the finned heat sinks. Louvres on the top and bottom covers would also reduce the internal air heat load and the temperature rise of the front panel.

Redesign of the power semiconductor mounting provisions and thermal control, resonant capacitors and filter capacitors would also reduce the electrical component weight.

Explorator work should also be performed on an alternate series resonant inverter concept proposed by Dr. F. C. Schwarz in reference [7], (United States Patent 4,096,557).

In this concept, the three phase rectification and low frequency input filter would be eliminated and low frequency electromagnetic interference filter would be greatly reduced.

With the improved cooling, redesign components and new circuit configuration, the total weight of the AC-DC Power Processor would be reduced from 88.8 lbs. to 55 lbs. and still maintain the same component operating temperatures.

7. REFERENCES

[1] Schwarz, F. C., "A Method of Resonant Current Pulse Modulation for Power Converters," IEEE Transactions on Industrial Electronics & Control Instrumentation, Vol. IECI-17-3, May 1970, pp. 209-220.

[2] Cronin, D.L., "2800 Watt Series Inverter DC Power Supply," Power Conditioning Specialist Conference, Pasadena, Calif., 1971, pp. 117 through 123.

[3] Yu, Y., et. al., "The Application of Standardized Control and Interface Circuits to Three DC to DC Power Converters," IEEE Power Electronics Specialists Conference Record, 1973, pp. 237-248.

[4] Cronin, D. L., "Power Supply PP-6418( )/U," Research & Development Technical Report ECOM-0245-F, U. S. Army Electronics Command, Fort Monmouth, N.J.

[5] Cronin, D. L., & Schoenfeld, A.D., "Development of a Uninterrupted Power System - AC & DC to DC Converter," NASA CR134497, Lewis Research Center.

[6] Biess, J. J., & Dudley, W., "AC-DC Power Processing Module for Military Digital Equipment Power Subsystem," IEEE 1979 National Aerospace and Electronics Conference, pp. 509-516.

[7] Schwarz, F. C., "Controllable Four Quadrant AC to AC and DC Converter Employing an Internal High Frequency Series Resonant Link," United States Patent No. 4,096,557, dated June 20, 1978.

APPENDIX A - PARTS LIST

The electrical parts list is presented for the following modular subassemblies:

- Front Panel
- A1 Printed Wiring Board Assembly
- A2, A3 Left and Right Side Panel
- A4 Rear Panel

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CKT REF	ITEM NO.
			2	RA20L ASB252A		RESISTOR, VARIABLE 2.5K	MIL-R-19	R1,R2	1
			4	FHL 17G1		FUSE HOLDER	MIL-F-19207/8	XF1 THRU X F4	2
			4	313.250		FUSE	LITTLE FUSE	F1-F4	3
									4
									5
									6
									7
			1	LH 74/1		LAMP HOLDER	MIL-L-3661/6	XDSI	8
			1	LC 13RN2		LENS	MIL-L-3661/13	XDSI	9
			1	MS2 5252-2D		LAMP		DSI	10
									11
			1	5226-8941		METER	WESTON	MI	12
			1	MS25308-262		SWITCH		SI	13
			1	M39010/05-255		CIRCUIT BREAKER		CBI	14
			1	CD2-B3		CIRCUIT BREAKER	HEINEMAN	CB2	15
									16
									17

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SIZE	CODE IDENT NO.		REV
A	11982	3.2 KW AC to DC POWER PROCESSOR (FRONT PANEL)	
		SHEET	

SYSTEMS 444 ...

PARTS LIST

QTY REQD PER ASSY -1	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC	REF DES	ZONE	ITEM NO.
1		D295083-1	PWE					1
1		D295085-1	VARIABLE RESISTOR ASSY					2
4		HA2-2520-2	OPER AMP		HARRIS	[illegible]-AR4		3
2		M39003/01-2374	CAPACITOR		MIL-C-39003/1	[illegible] 2		4
2		M39014/02-1230			MIL-C-39014/2	C3,C5		5
1		M39003/01-2356			MIL-C-39003/1	C4		6
1		M83421/01-5-246M			MIL-C-83421/1	C6		7
2		CM06FD102JP3			MIL-C-5-18	C7,C8		8
8		M39014/05-2927			MIL-C-39014/5	C9-16		9
13		M39014/05-2891			MIL-C-39014/5	C17-25,C29-C24		10
1		CY30C103F			MIL-C-11272/4	C26		11
1		M39014/01-1255			MIL-C-39014/1	C27		12
1		M39014/05-2843			MIL-C-39014/5	C31		13
3		M39014/02-1258			MIL-C-39014/2	C33,C32,C36		14
1		M39003/01-2766			MIL-C-39003/1	C35		15
1		M39014/01-1250			MIL-C-39014/1	C37		16
1		M39014/05-2213	CAPACITOR		MIL-C-39014/5	C39		17
1		S3 BR1	BRIDGE RECTIFIER		SEMTECH	CR1		18
4		JAN 1N5618	DIODE		MIL-S-19500/427	CR2-CR5		19
13		JAN 1N3600	DIODE		MIL-S-19500/231	CR10-CR22		20
2		SBR1F	BRIDGE DIODE		SEMTECH	CR23,CR24		21
1		M24308/3-3		25 PIN	CANNON	J1		22
1		M24308/1-4		37 SOCKET	CANNON	J2		23
1		RER75F3922M	RESISTOR		MIL-R-39009/1	R1		24
3		RNC55H2152FR			MIL-R-55182/1	R2, R7, R11		25
1		RCR07G101JS			MIL-R-39008/1	R3		26
1		RNC60H4023FS			MIL-R-55182/3	R4		27
2		RNC60H4993FS			MIL-R-55182/3	R5, R8		28
								29
1		RNC55H7873FR			MIL-R-55182/5	R9		30
1		RNC55H5761FR			MIL-R-55182/1	R12		31
1		RCR07G752JS			MIL-R-39008/1	R13		32
1		RCR07G304JS	RESISTOR		MIL-R-39008/1	R14		33

A-31

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SIZE	CODE IDENT NO		REV
B	11982	PARTS LIST - A1 PRINTED WIRING BOARD	A
SCALE NONE		SHEET 1 of 3	

SYSTEMS 5041 REV. 11-72

PARTS LIST

QTY REQD PER ASSY				CODE IDENT NO.	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC	REF DES	ZONE	ITEM NO.
			-1								
			1		RCR07G[illegible]JS	RESISTOR		MIL-R-39008/1	R15		34
			1		RCR07G512JS			MIL-R-39008/1	R16		35
			8		RWR80S1210FR			MIL-R-39007/6	R17-R24		36
			2		RCR07G512JS			MIL-R-39008/1	R25, R50		37
			1		RNC55H6491FR			MIL-R-55182/1	R26		38
			1		RNC55H4990FR				R27		39
			1		RNC55H1003FR				R28		40
			1		RNC55H4991FR				R29		41
			1		RNC55H4531FR				R30		42
			1		RNC55H3332FR				R32		43
			1		RNC55H8062FR				R33		44
			1		RNC55H2612FR				R34		45
			1		RNC55H6191FR				R36		46
			1		RNC55H5111FR				R37		47
			2		RNC55H1002FR				R38, R45		48
			1		RNC55H2001FR				R39		49
			1		RNC55H[illegible]962FR				R42		50
			1		RNC55H5621FR				R43		51
			1		RNC55H4641FR			MIL-R-55182/1	R44		52
			1		RWR81S1960FR	RESISTOR		MIL-R-39007/4	R40		53
			1		RCR07	RESISTOR, SELECT IN TEST		MIL-R-39008/1	R46		54
			1		RCR07G222JS	RESISTOR		MIL-R-39008/1	R47		55
			1		RNC55H5[illegible]2FR	RESISTOR		MIL-R-55182/1	R48		56
			1		RNC55H4[illegible]32FR	RESISTOR		MIL-R-55182/1	R51		57
											58
											59
											60
											61
			1		D295093-1	TRANSFORMER			T1		62
											63
											64
			2		LM[illegible]	4 CH[illegible] AMPLIFIER		NATIONAL	U1, U10		65
			1		JAN 4N24	OPTICAL ISOLATOR		MIL-S-19500/486	U2		66

TRW SYSTEMS GROUP
ONE SPACE PARK · REDONDO BEACH · CALIFORNIA 90278

SIZE	CODE IDENT NO.		REV
B	11982	PARTS LIST - A1 PRINTED WIRING BOARD	A
SCALE NONE		SHEET 2 of 3	

QTY REQD PER ASSY -1	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC	REF DES	ZONE	ITEM NO.
4		SN55452BJP	DUAL DRIVER		T.I.	U3,U4, U5,U6		67
2		SN54L04	HEX INVERTER		T.I.	U7, U8		68
1		CD4018AF	RING COUNTER		RCA	U9		69
								70
								71
1		μA7812KM	VOLTAGE REGULATOR 12V		FAIRCHILD	VR1		72
1		M38510/107-01-CYC	VOLTAGE REGULATOR 5V		MIL-M-38510	VR2		73
5		JAN 1N4573A	REF ZENER		MIL-S-19500/452	VR3-VR7		74
								75
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								99

TRW SYSTEMS GROUP
ONE SPACE PARK · REDONDO BEACH · CALIFORNIA 90278

SIZE	CODE IDENT NO		REV
B	11982	PARTS LIST - A1 PRINTED WIRING BOARD	A
SCALE	NONE	SHEET 3 of 3	

SYSTEMS 2041 REV 11-72

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CKT REF	ITEM NO.
			8	RCR20GF 101JS		RESISTOR, 100 OHM ±5%, 1/4 W	MIL-R-39008/2	A2 & A3 R1,R2,R5,R6	18
			8	RE65G 2000		RESISTOR, 200 OHM, 10W	MIL-R-18546/1	A2 & A3 R3,R4,R7,R8	19
									20
									21
			4	86F241L		CAP, 150MF, 450V	G.E.	A2 & A3 C1, C7	22
			8	CMR1A102202K		CAP, .002MF ±10%, 1000V	CUSTOM	A2 & A3 C2,C3,C8,C9	23
			8	CR2004G724 JXL		CAP, .72MF ±5%, 1000V	COMP. RESEARCH	A2 & A3 C4,C5,C10,C11	24
			4	92F227ALA		CAP, 2100MF, 40V	G.E.	A2 & A3 C6, C12	25
			8	M39014/02-1258		CAP, .01MF ±10%, 200V	MIL-C-39014/2	A2 & A3 C13,C14,C15,C16	26
			1	D295095-2		POWER TRANSFORMER	A2T3		27
			8	D295096-1		SCR DRIVER TRANSFORMER	A2T1, T2, T4, T5 A3T1, T2, T4, T5		28
			3	D295095-1		POWER TRANSFORMER	A2T6 A3T3, A3T6		29
			1	D295097-1		CURRENT SENSE TRANSFORMER	A3T7		30
			3	D295094-1		RESONANT INDUCTOR	A2L2 A3L1 & L2		31
			1	D295094-2		RESONANT INDUCTOR	A2L1		32
			8	SCPAS 2A		DIODE - 100 AMP	SEMTECH	A2 & A3 CR1-CR4	33
			8	T507-084084 AQ		THYRISTOR	WESTINGHOUSE	A2 & A3 VR1-VR4	34

TRW SYSTEMS GROUP

SIZE	CODE IDENT NO.		REV
A	11982	3.2 KW AC to DC POWER PROCESSOR (A2, A3 SIDE PANEL)	
		SHEET	

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CKT REF	ITEM NO.
			1	RE70[illegible]5R0		RESISTOR, 24.9 OHMS, 20W	MIL-R-18546/1	A4R1	35
			2	RCR32GF204JS		RESISTOR, 200K ±5% 1 W	MIL-R-39008/3	A4R2,R3	36
			1	9992-0041239		SHUNT, 100 MV	WESTON	A4R4	37
			1	RNC55H 4992FR		RESISTOR, 49.9K ±1%, 1/8 W	MIL-R-55182/1	A4R5	38
			2	RE70N25R0		RESISTOR, 24.9 OHMS, 20W	MIL-R-18546/1	A4R6,R7	39
			1	RWR80SR500FR		RESISTOR, 0.5 OHMS ±1%, 2W	MIL-R-39007/8	A4R8	40
			1	QWLD 02R22N13P		CONNECTOR	BENDIX	J1	41
			1	MS17346R 32NIS		CONNECTOR		J2	42
									43
			3	RC60F103		FEED-THRU CAPACITOR .01MF +20% 250V	RF INTERONICS	A4FL1, FL2,FL3	44
			6	AB12E405KSC		CAP, 4MF, 400V	COMP. RESEARCH	A4C1 THRU C6	45
			6	92F233 AMA		CAP, 5500MF, 40V	G.E.	A4C7 THRU C12	46
			2	M83421/01-2-282M		CAP, 2MF ±10%, 50V	MIL-C-83421/1	A4C13, C14	47
			5	AE12B906 KSC		CAP, 80MF, 50V	COMP. RESEARCH	A4C15 THRU C19	48
									49
									50
									51

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	CODE IDENT NO.		REV
A	11982	3.2 KW AC to DC POWER PROCESSOR (A4 REAR PANEL)	
		SHEET	

AD-A081 545 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA --ETC F/G 10/2
AC-DC POWER PROCESSOR, TYPE I.(U)
NOV 79 J J BIESS DAAB07-76-C-1336
UNCLASSIFIED TRW-29518-6001-RU-00 DELET-TR-76-1336-F NL

2 OF 2
AD A081545

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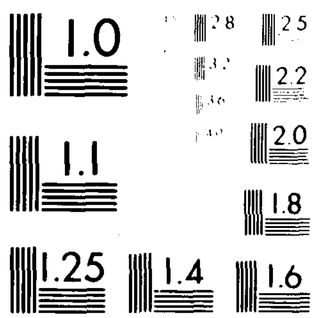

MICROCOPY RESOLUTION TEST CHART

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CKT REF	ITEM NO.
			1	D295086-1		EMI INDUCTOR		A4L1	52
			3	D295087-1		EMI INDUCTOR		A4L2 L3, L4	53
			3	D295088-1		EMI INDUCTOR		A4L5, L6, L7	54
			1	D295089-1		INPUT FILTER		A4 L8	55
			1	D295090-1		100A OUTPUT INDUCTOR		A4 L9	56
			1	D295092-1		SENSE EMI FILTER		A4 L11	57
									58
									59
			1	SC3AS6A		3 ϕ BRIDGE	SEMTECH	A4CRI	60
			2	JAN IN 2846B		DIODE	MIL-S-19500/114	A4VRI, VR2	61
									62
			1	D295097-1		TRANSFORMER		A4T1	63

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	CODE IDENT NO.		REV
A	11982	3.2 KW AC to DC POWER PROCESSOR (A4 REAR PANEL)	
		SHEET	

SYSTEMS 2444 REV. 2-67

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